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Scaling
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Concrete Aggregate
Evaluation and Effluent
on Resistance to

43
24

T H E S I S

CONCRETE AGGREGATE EVALUATION

and

EFFECT OF SURFACE AND FINISH ON RESISTANCE TO SCALING

Submitted as the Partial Fulfillment
of the
Requirements for the Degree of
Master of Science

by

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Under the direction of
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PREFACE

The quality of any concrete mix is fundamentally based on the quality of the materials which constitute the mix. Thus, assuming proper design and curing procedures are followed, the physical properties which are to be desired in a concrete mix, such as strength and durability, depend on the physical properties of the cement, sand, and gravel which are used to make the mix.

In most cases several different sources of sand and gravel exist in any one general area. Each source or pit may give aggregates of varying size and of varying physical properties. The problem arises, then, which aggregate is best suited to make good concrete.

This decision is not a simple one to make. If there are several different sources of sand and several of gravel each type must be put through all of the standard American Society for Testing Materials tests first, individually, to determine their separate physical properties and then, in concrete mixes, using different combinations of sand and rock. Only after a very comprehensive series of tests on the various mixes can a reliable judgment be made as to which aggregate is most suitable for different job conditions.

In the investigation to be reported in this paper an evaluation of the different aggregates available in the Calgary and Edmonton areas is presented. This evaluation is presented on the basis of various sand and rock studies. The sand studies were made using one particular rock for every mix design, and the rock studies were made using one particular sand. In every case mixes were tested for compressive strength, for flexural strength, and for durability.

It should here be emphasized that the problem of properly evaluating an aggregate of necessity covers such a wide scope that, only by repeated testing, can a final general conclusion be made. In the following work as many tests were run as could possibly be done in the time allowed. Though they serve as a very sound basis for making decisions it is felt that many more tests would be of considerable advantage to check and to confirm any doubtful data.

A second phase of this paper is an investigation of surface scaling in concrete due to CaCl_2 which is frequently used to remove ice from pavements. Some work was done on this project last year in connection with air-entrainment studies⁽¹⁾, but since the results were not as favorable as those reported by Portland Cement Association⁽²⁾, a further series of tests were carried out to investigate the effect of increased cement content and type of surface finish, as well as entrained air, on the resistance of concrete to CaCl_2 scaling.

(1) An Investigation of Air-Entrainment in Concrete and its Effect on Durability-- Thesis for M.Sc. Degree by K.R. Lauer, University of Alberta, 1948.

(2) Proceedings of American Concrete Institute , Vol. 33, 1937--
'Effect of Calcium and Sodium Chlorides on Concrete
When Used for Ice Removal'--H.F. Gonnerman

PART I

LABORATORY EQUIPMENT

A. SONIC EQUIPMENT⁽¹⁾

The modulus of elasticity of concrete beams can be determined by a dynamic method. This method requires the measurement of the natural or resonant frequency of prismatic bars. Having determined the resonant frequency, a solution of the dynamic modulus of elasticity, 'E' may be obtained by substitution in the following equation:

$$E = \frac{4\pi^2 l^4 f^2 \rho}{k^2 m^4} \times T$$

- where,
- E = dynamic modulus of elasticity, pounds per square inch
 - ρ = mass density -- slugs/inch
 - l = length of specimen--inches
 - f = resonant frequency
 - k = radius of gyration of the section about an axis perpendicular to the plane of bending
($k = \frac{t}{\sqrt{12}}$ for rectangular cross sections)
 - t = height of beam
 - m = number depending on mode of vibrating beam and on ratio $\frac{d}{L}$
= 4.73 for fundamental and small ratios of $\frac{d}{L}$
 - T = correction term depending on ratio of thickness to length and on Poisson's Ratio
= 1.4 for the specimens tested

(1) A more detailed description of the Sonic Apparatus and the Accelerated Freeze-Thaw Apparatus may be found in a thesis written by K.R. Lauer for M.Sc. Degree at the University of Alberta, 1948, entitled, 'An Investigation of Air-Entrainment in Concrete and its Effect on Durability'.

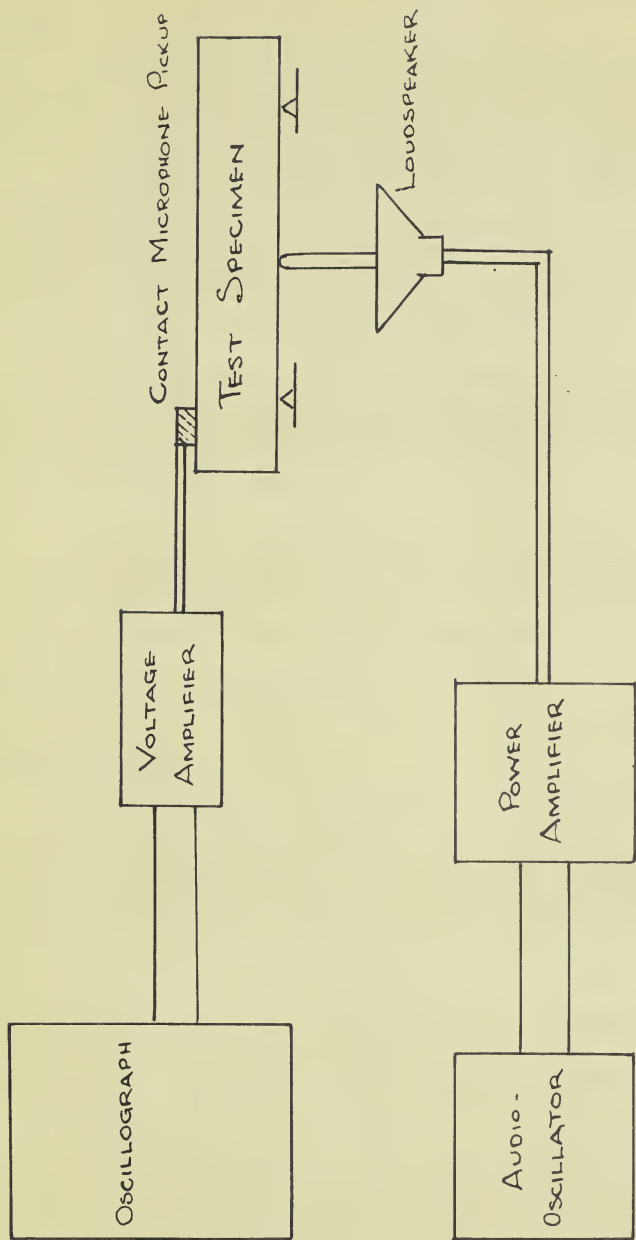


FIGURE 1. SCHEMATIC DIAGRAM OF SONIC APPARATUS

Fig. 1

Apparatus

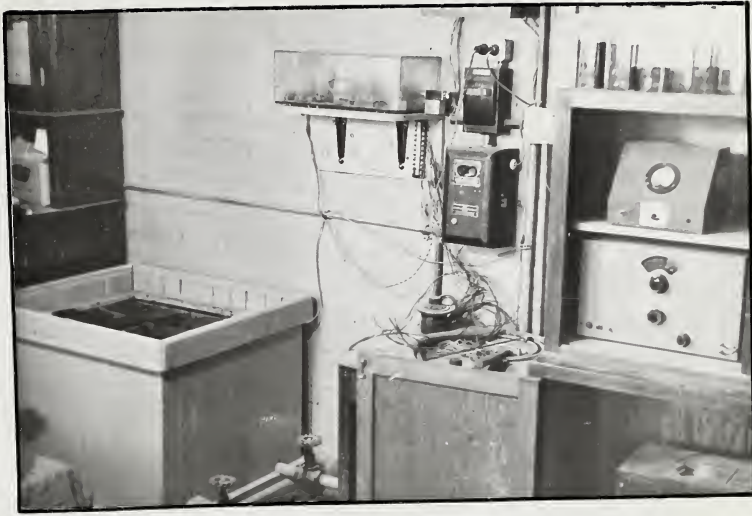
The beam to be tested is supported on two knife edges at its nodal points, (0.224 of its length from each end).

The driving circuit consists of a variable frequency audio oscillator and a driving unit. The oscillator is a Hewlitt Packard, No. 11012, calibrated to read within $\pm 2\%$ of the true frequency over its range of use, (550 to 6000 cycles). The oscillator is coupled through a transformer to an 8-inch, magnet-type loudspeaker, a rod being cemented to the voice coil of the speaker for transmitting the vibration to the specimen.

The pickup circuit consists of a pickup unit, an amplifier, and a meter. The pickup unit is an electro-magnetic type which generates a voltage proportional to the amplitude or velocity of vibration of the test specimen.

Testing Procedure

The specimen is supported at the nodal points. The driver is then brought into contact with the beam. The pickup is held in place at one end of the beam by a strong rubber band. The frequency of the oscillator is then varied until the amplitude of vibration of the specimen reaches a maximum as shown by the meter. The reading on the frequency dial is then recorded as the resonant frequency of the beam under test.



FREEZE - THAW & SONIC APPARATUS



AUTOMATIC SWITCHES



SONIC APPARATUS

FIGURE 2.

B. AUTOMATIC ACCELERATED FREEZING AND THAWING APPARATUS FOR CONCRETE

The apparatus consists essentially of three tanks:

1. A specimen tank
2. A cold tank and refrigeration unit
3. A thaw tank and heating unit

1. Specimen Tank

The inside dimensions of this tank are 27 inches long by 21 inches wide by 21 inches deep. It is designed to hold 4 racks each of which is capable of holding 3 specimens, making a total of 12 specimens in the tank at one time. Solutions are pumped into the specimen tank through two perforated pipes each running the length of the tank. One is for the incoming, cold solution and the other is for the thaw solution. There is a $1\frac{1}{4}$ "-diameter drain pipe in the bottom of the specimen tank, and also an overflow pipe which is a $1\frac{1}{4}$ "-diameter pipe with the upper half removed. This defines the upper level of the flowing solution.

2. Cold Tank and Refrigeration Unit

The inside dimensions of this tank are 48 inches long by 24 inches wide by 24 inches deep. It is insulated with 4 inches of cork. Four refrigeration plates in units of two are supported 6 inches above the bottom of the tank. The refrigeration is performed by a 2 horse power, 220 volt, 60-cycle, 3-phase, water-cooled condensing unit using Freon F-12 as the refrigerant. This unit which has a capacity of 10,000 BTU/hour, has a thermostat control set at -20°F . It is adequate equipment for the 75 gallons of fluid which the tank contains.

3. Thaw Tank and Heating Unit

This is a circular tank, 24 inches in diameter by 48 inches

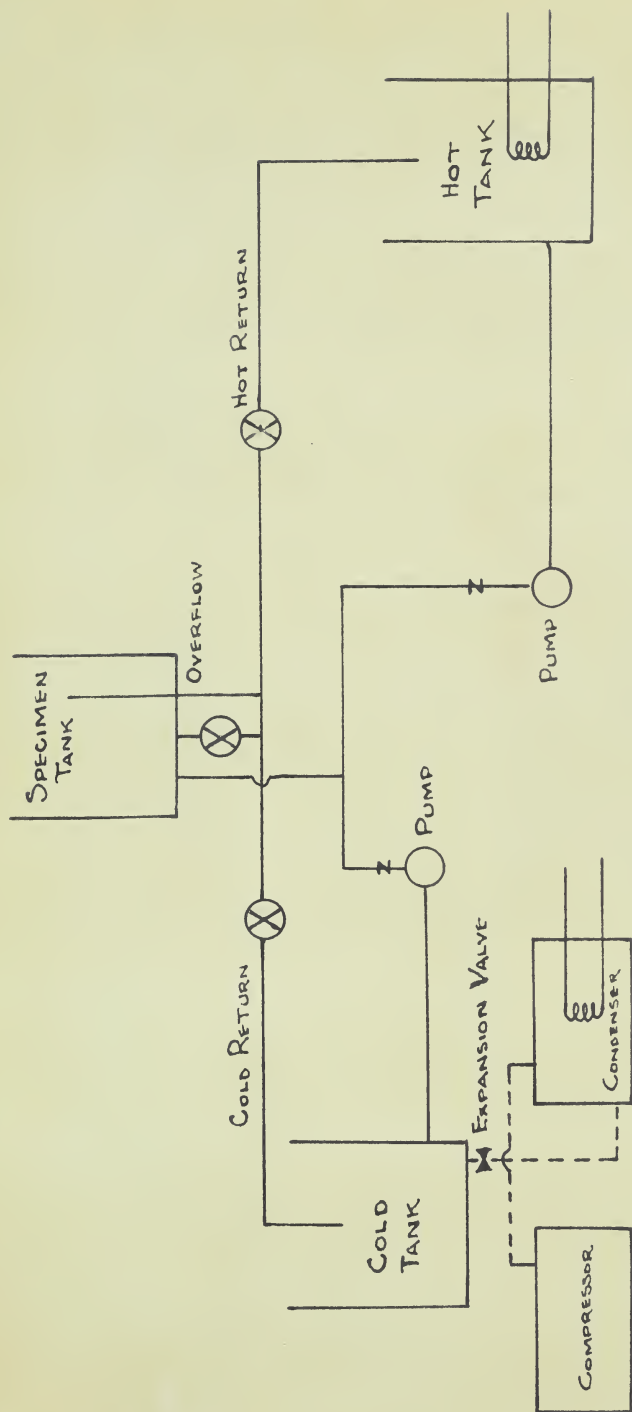
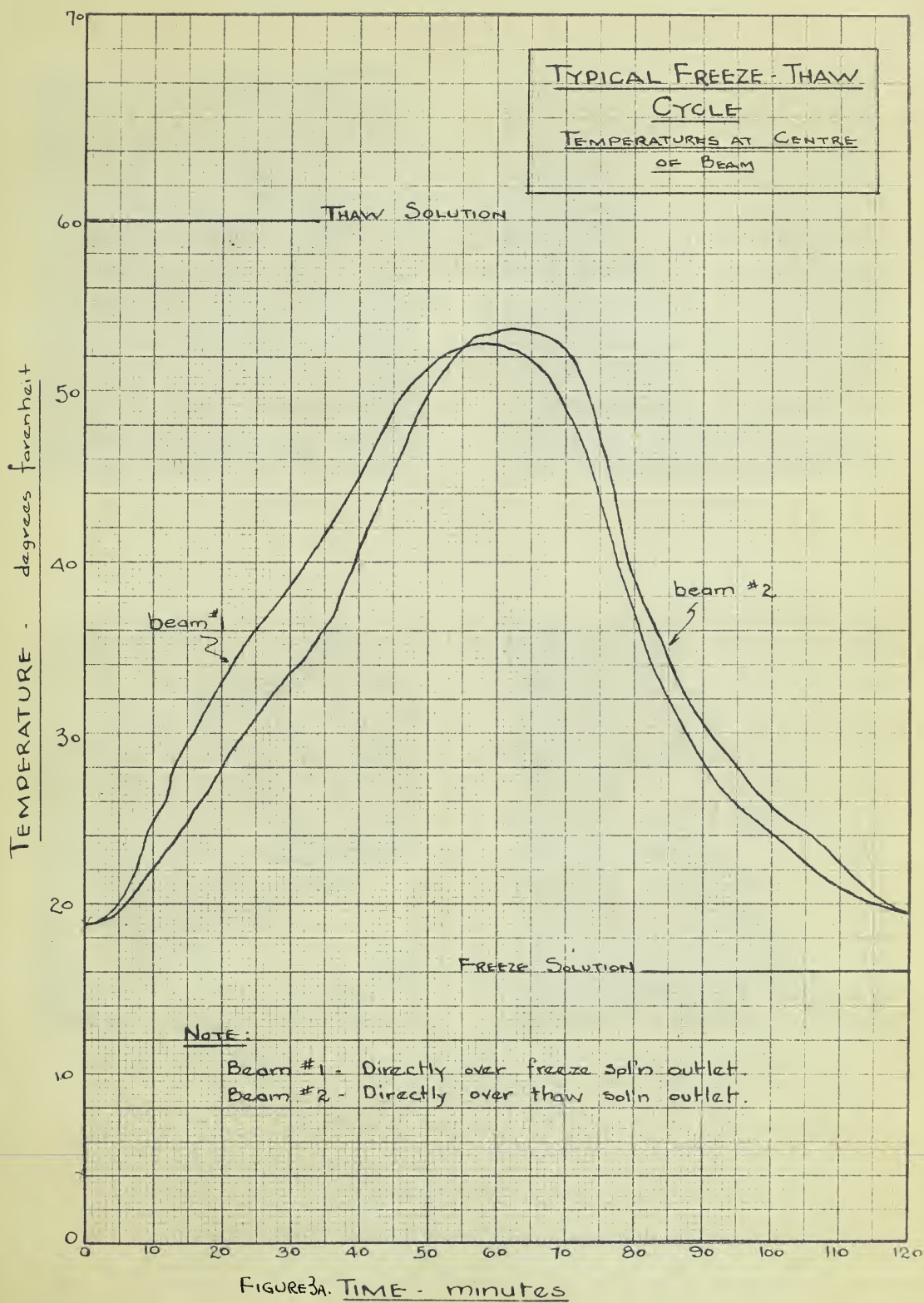


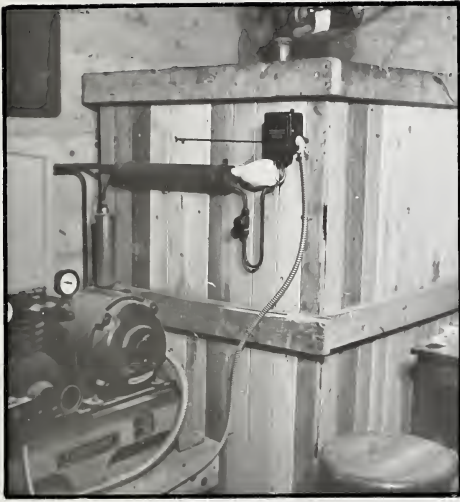
FIGURE 3. SCHEMATIC DIAGRAM OF FREEZE-THAW APPARATUS

high. Two 1000 watt, 200 volt immersion heaters are installed diagonally across from each other, 6 inches above the bottom of the tank. The thermostat control in this apparatus is set at 70°F.

TABLE I
SEQUENCE OF OPERATION OF VALVE AND PUMPS

Elapsed Time			Operation
Hr.	Min.	Sec.	
0	0	0	Drain valve closes
0	0	30	Cold return valve opens
0	1	0	Cold pump starts
0	54	0	Cold pump stops
	54	2	Drain valve opens
1	0	0	Drain valve closes
1	0	30	Thaw return valve opens
1	1	0	Thaw pump starts
1	54		Thaw pump stops
1	54	2	Drain valve opens
2	0	0	Drain valve closes





COLD TANK



HOT TANK



SPECIMEN TANK



CURING ROOM

FIGURE 4

Concrete Mixers

Two mixers are available in the concrete laboratory.

The old laboratory mixer is a 0.5 cubic ft., tilting drum type mixer. It was designed and built at the University of Alberta as a scale model of the type of mixer used in the construction of the Grand Coulee Dam in Colorado. The mixer is powered by a $1\frac{1}{3}$ horse power electric motor and is operated at a speed of 20 revolutions per minute. A mixing time of five minutes was used with this mixer.

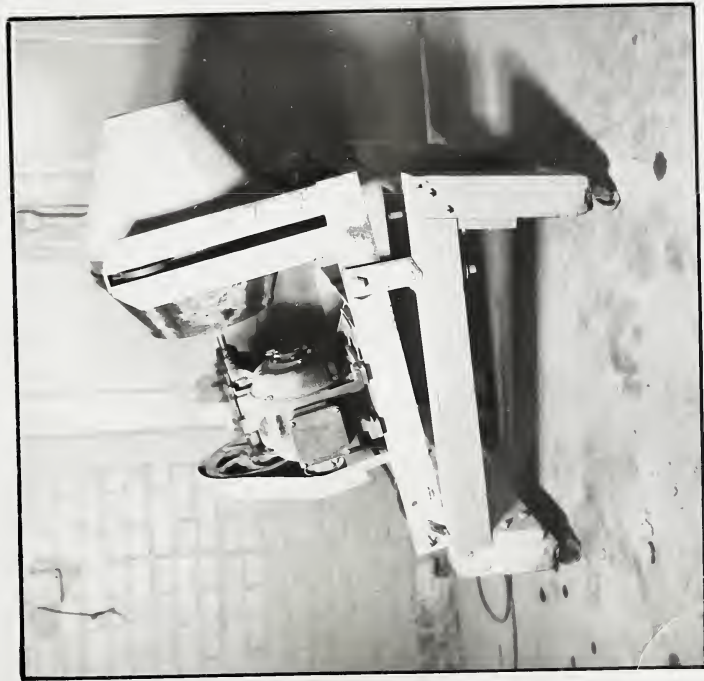
The new laboratory mixer is a $1\frac{1}{2}$ cubic ft., Lancaster Mixer, Type SKG, Serial No.303, manufactured by Volta Manufacturing Company, Ltd., Welland, Ontario. It is powered by a 3 horse power Wagner Electric Motor and is operated at a speed of 20 revolutions per minute. This mixer is designed for laboratory work having an open, circular, removable type of drum in which the concrete is mixed. Vertical mixing blades rotate in an opposite direction to the drum and can be raised vertically to allow removal of the drum.

Testing Machine

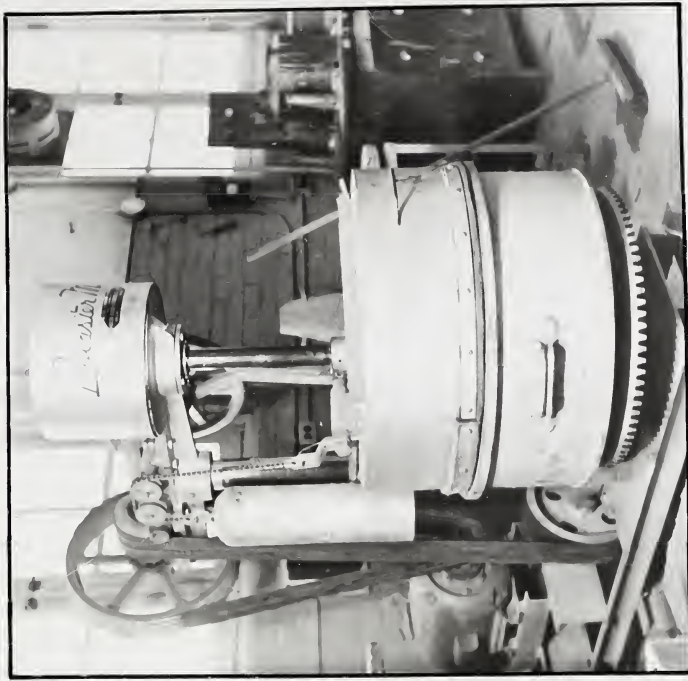
The load testing machine which was used for measuring compressive strengths of cylinders and flexural strengths of beams is a Baldwin Southwark Tate-Emery Testing Machine. It is a hydraulic, reaction-type load testing machine having a maximum capacity of 200,000 pounds. The machine has a pneumatic load indicator and also a load-pacer which enables the adjustment of the rate of loading to any desired number of pounds per second. The load indicator has three scales:

0 - 10,000 lbs.	Low Scale
0 - 50,000 lbs.	Medium Scale
0 - 200,000 lbs.	High Scale

This allows for the choice of whichever scale is required to give the maximum deflection of the needle thus enabling greater accuracy in reading.

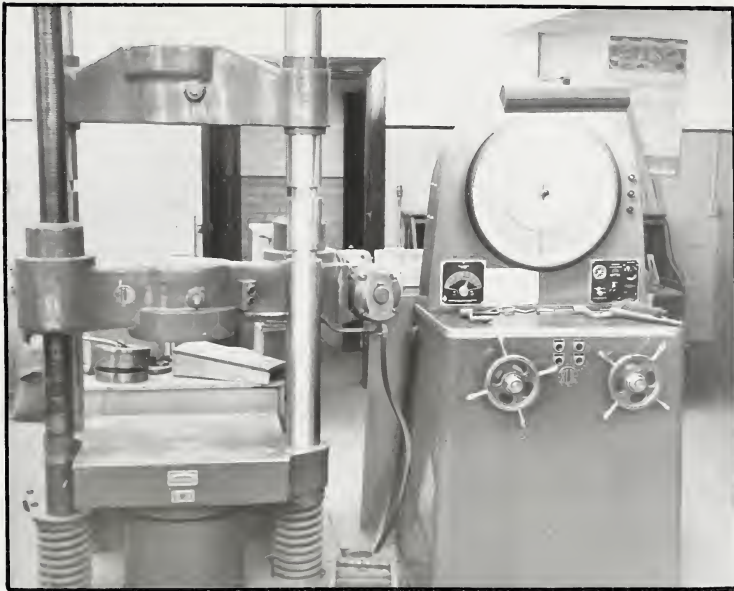


TILTING DRUM MIXER

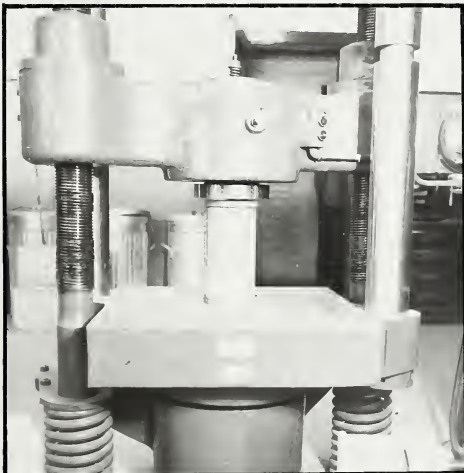


LANCASTER MIXER

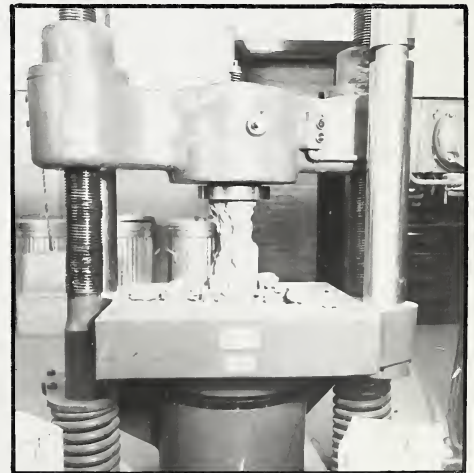
FIGURE 5.



BALDWIN SOUTHWARK EMERY-TATE
TESTING MACHINE



BEFORE TEST...



... AFTER TEST

FIGURE 6.

PART II

AGGREGATE INVESTIGATION

INTRODUCTION -- (SYNOPSIS)

The purpose of this investigation was to analyze, in as comprehensive a manner as possible, the physical properties of several different types of sands and gravels obtained from the Edmonton and Calgary areas.

The first step was to perform the standard A.S.T.M.⁽¹⁾ Aggregate Tests. Each material was thoroughly investigated following the procedures outlined in the booklet, 'A.S.T.M. Standards on Mineral Aggregates, Concrete, and Nonbituminous Highway Materials', published by A.S.T.M. in September, 1948.

The next step was to investigate actual concrete mixes using the aggregates to be tested. At this point the problem arose of how to proportion the mix so that the aggregate tested would be given the best possible opportunity to show its optimum physical properties. Because recent publications⁽²⁾ have advocated the 'Fineness Modulus' method of proportioning mixes in favor of the standard American Concrete Institute method of mix design⁽³⁾, an investigation was carried out to see whether this 'Fineness Modulus' method of design gave better test results.

On the basis of the above investigation a series of Sand Evaluation Tests were carried out in which a particular gravel was used

(1) American Society for Testing Materials

(2) 'Revised Application of Fineness Modulus in Concrete Proportioning' --H.L. Kennedy, Dewey and Almy Chemical Co.

(3) Journal of the American Concrete Institute--November, 1943

with all of the different types of sands, followed by a series of Rock Evaluation Tests in which a particular sand was used with all of the different types of rock to be tested.

Aggregates were evaluated on the basis of compressive strength tests, flexural tests and durability in the automatic accelerated freeze-thaw apparatus.

CHAPTER I

PRELIMINARY MATERIALS TESTS

The following aggregates were tested:

From the Calgary Area--

Dewinton Sand
River Sand
Clarke Sand
Alberta Transit Mix Gravel

From the Edmonton Area--

Doncaster Washed Sand
Doncaster Pit Run Sand
Elk Island Sand
O.K. Construction Company Gravel
Bennett and White Gravel
Alberta Concrete Products Gravel

The cement used in all cases was Standard Exshaw Portland Cement.

All tests were repeated 4 times on each aggregate, and the results are the average of the 4 tests.

A. CEMENT TESTS

The cement used for all the testing was Standard Exshaw Portland Cement. In order to eliminate as much as possible the chance that any strength variations might be due to variations in the physical properties of the cement from bag to bag, a sufficient number of bags were opened and thoroughly mixed together to get a uniform total batch of cement. This batch was stored in a tight container and used for every mix.

A chemical analysis was made of a sample of the mixed batch of cement.

Silicon Dioxide (SiO_2)	=	22.01%
Aluminum Oxide (Al_2O_3)	=	5.69%
Ferric Oxide (Fe_2O_3)	=	2.95%
Calcium Oxide (CaO)	=	63.21%
Magnesium Oxide (MgO)	=	2.87%
Sulphur Trioxide (SO_3)	=	2.07%
Loss on Ignition	=	0.76%
Sodium and Potassium Oxide	=	0.44%
Insoluble Residue	=	0.45%

Note that the amount of the alkalis Sodium and Potassium Oxides is 0.44% in the cement used. Amounts greater than 0.50 to 0.60 may be detrimental.

From the above analysis the compound composition was computed. This is shown in the following table which compares the allowable maximum and minimum values of each.

Percentage Compound Composition for
Type I A.S.T.M. Standard Portland Cement

	C ₃ S	C ₂ S	C ₃ A	C ₄ AF	CaSO ₄	Free CaO	MgO	Ig.Loss
Max.	54	43	14	10	3.3	1.5	3.8	2.3
Min.	29	22	9	6	2.2	0.0	0.7	0.6
Exshaw	36.5	35.8	10.0	9.0	3.5	1.0	2.87	0.76

TABLE 2

Physical Properties of Cement

Specific Gravity	Soundness Pats	Time of Set Initial	Final	Water for Consistency
3.13	O.K.	2 hrs. 15 mins.	6 hrs.	26.6%

TABLE 3

Compressive Strength Tests - C109-44

Proportions		Flow %	Compressive Strength p.s.i.		
			3 Day	7 Day	28 Day
<u>Trial 1</u>	Cement = 500 gms.	100%	1042	1838	2375
	Std. Sand = 1375 gms.		1172	1238	2762
	Water = 300 gms.				
<u>Trial 2</u>	Cement = 500 gms.	100%	1015	1662	2912
	Std. Sand = 1375 gms.		900	1488	3038
	Water = 300 gms.				

TABLE 4

Tensile Strength Tests -- C190-44

	Proportions	Tensile Strength p.s.i.		
		3 Day	7 Day	28 Day
<u>Trial 1</u>	Cement = 300 gms.			
	Sand = 900 gms.	284	300	392
	Water = 130.8 gms.	256	288	380
<u>Trial 2</u>	Cement = 300 gms.	255	370	407
	Sand = 900 gms.	260	328	385
	Water = 130.8 gms.			

TABLE 5

B. SAND TESTS

Physical Properties of Fine Aggregate

Material	Absorption (24 Hr.) % by Wt.	Specific Gravity			Coal & Lignite % by Wt.	Silt Content % by Wt.	Color Test
		Bulk	Bulk (Sat)	Appar- ent			
Doncaster Washed Sand	1.22	2.58	2.61	2.66	0.01	0.85	# 3
Doncaster Pit Run Sand	1.01	2.60	2.62	2.66	0.02	0.98	# 2
Elk Island Sand	1.17	2.57	2.60	2.55	0.008	0.79	# 2
Dewinton Sand	2.10	2.49	2.55	2.60	0.04	3.20	# 3
River Sand	1.06	2.55	2.58	2.62	0.085	0.90	#1
Clarke Sand	2.48	2.52	2.58	2.67	0.045	9.0	# 1

TABLE 6

Sieve Analysis
A.S.T.M. C 136-46

Material	Cumulative Percent Retained on Screen Indicated						F.M.
	# 4	# 8	# 16	# 30	# 48	# 100	
Doncaster Washed Sand	5.4	9.6	15.3	41.9	91.2	98.3	2.61
Doncaster Pit Run Sand	7.3	18.1	36.1	69.3	92.8	98.2	3.22
Elk Island Sand	11.8	24.6	44.2	74.2	95.2	98.7	3.48
Dewinton Sand	3.3	5.0	11.7	49.5	91.8	95.5	2.57
River Sand	3.9	28.5	49.2	61.3	84.8	97.1	3.25
Clarke Sand	3.5	8.2	15.2	27.4	63.7	84.8	2.02

TABLE 7

Cube Tests - A.S.T.M. C87-47

Material	Date Cast	Amt. of Sand Added Grams	Compressive Strength		
			3 Day psi	7 Day psi	28 Day psi
Doncaster Washed Sand	July 9/48	1435	1069	2212	2188
	July 9/48	1502	1052	2125	2037
	July 10/48	1464	1450	1831	3020
	July 12/48	1439	--	2050	3862
Doncaster Pit Run Sand	Jan. 10/49	1621	1150	2000	2380
	Jan. 10/49	1658	1275	2130	2567
Elk Island Sand	July 15/48	1864	1430	3093	3935
	July 15/48	1927	1251	2407	3837
	July 15/48	1820	931	2418	3812
	July 16/48	2086	1231	2518	3838
Dewinton Sand	Aug. 25/48	1108	1406	2531	4775
	Sept. 7/48	1312	1491	2244	3156
River Sand	Aug. 25/48	1598	1569	3175	5150
	Sept. 7/48	1700	2012	3113	4762
Clarke Sand	Aug. 25/48	891	1263	2690	4306
	Sept. 7/48	1016	1431	2288	3720
Standard Ottawa Sand	Sept. 7/48	1627	1231	2206	4043
	Aug. 12/48	1657	1606	2407	4544
	June 15/48	1617	1000	2050	4150
	June 18/48	1546	1120	2100	4300

Note: Each value shown is the average of 2 cubes.

TABLE 8

C. COARSE AGGREGATE TESTS

Physical Properties of Coarse Aggregate

Material	24 Hr. Abs'n. % By Wt.	Specific Gravity		
		Bulk S.G.	Apparent	Bulk (Sat.Sur.Dry)
O.K. Constn.	0.86	2.60	2.65	2.62
Bennett & White	1.55	2.55	2.66	2.59
Alta. Conc. Prod.	0.68	2.59	2.65	2.61
Alta. Transit Mix	0.72	2.64	2.69	2.65

Note: All values are the average of 2 tests.

TABLE 9

Sieve Analysis

A.S.T.M. C136-46

Material	Cumulative Percent Retained on Screen					
	1½"	1"	¾"	⅜"	# 4	F.M.
O.K. Construction	0	10.5	35.5	82.6	97.1	7.26
Bennett & White	0	0.9	17.2	92.7	99.9	7.10
Alta. Conc. Prod.	0	2.0	13.2	79.0	98.1	6.93
Alta. Transit Mix	0	1.0	10.6	81.8	99.0	

TABLE 10

CHAPTER II

FINENESS MODULUS INVESTIGATIONSummary of Kennedy⁽¹⁾ Report

This report advocates the principle of proportioning the amounts of fine and coarse aggregate on the basis of an 'Optimum Fineness Modulus'. The single index, known as 'Fineness Modulus', was originally conceived by Duff Abrams. It is computed from the standard sieve test simply by adding the cumulative percentages retained on every sieve up to, and including, the #100 sieve. For any particular type of sand and gravel combination there exists an Optimum F.M. This Optimum F.M. is taken from a series of tests run on the aggregate where, by varying the amounts of sand and rock, the combined F.M. of the mix is varied. Strength tests are plotted versus F.M. to give a curve of this type:

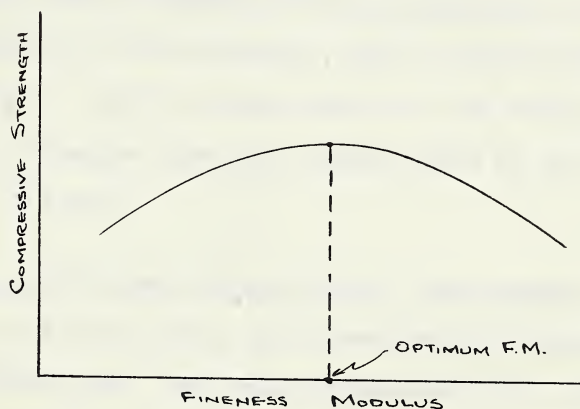


FIGURE 7.

From this series of curves the Optimum F.M. is taken.

(1) 'Revised Application of Fineness Modulus in Concrete Proportioning'--
H.L. Kennedy, Dewy and Almy Chemical Company.

and all future designs using that particular aggregate are based on combining sand and rock so as to get a combined F.M. equal to the optimum value.

The combined F.M. of a mix is found by the following formula:

$$\text{F.M.} = \frac{P_a M_a + (100 - P_a) M_b}{100}$$

where F.M. = Combined F.M. of sand and rock

P_a = % rock in mix

M_a = F.M. of rock

M_b = F.M. of sand

For the purposes of investigating the physical properties of different aggregates it was felt that, in order to get a fair comparison, each aggregate investigated must be given every opportunity to show its maximum potential desirable qualities.

In the case of designing the mix proportions for making comparative concrete, it was necessary, then, to take cognizance of the Kennedy Report. For if a design based on F.M. would give maximum compressive strengths, then that design should be the one used for our series of tests.

General Outline of 'Fineness Modulus Design' Investigation

Two sands were used in this investigation--Doncaster Washed Sand and Elk Island Sand. Each sand was combined with O.K. Construction Company rock in varying quantities such that the combined Fineness Modulus of the sand and rock would range from 4.8 to 5.8 in jumps of 0.2. This gave a series of mixes ranging from a very harsh, undersanded mix to a very fat, oversanded mix.

Two different cement factors were used for each mix:

- a) Cement to aggregate ratio of 1:8
- b) Cement to aggregate ratio of 1:5

A constant slump of 4" was to be maintained for every mix.

For each different mix a total of four cylinders were poured, one to be broken at 7 days, and three at 28 days, and two beams for accelerated freeze-thaw tests at 28 days.

The total number of different mixes poured was twenty-four. Twelve of those used Doncaster Washed Sand and twelve used Elk Island Sand.

Sample Calculation of Mix Proportioning for F.M. Tests

For F.M. = 4.8 using

O.K. Construction Rock (F.M. = 7.13)

Elk Island Sand (F.M. = 3.48)

For a 1:8 mix, that is, 1 part cement to 8 parts aggregate

$$\frac{P_a M_a + (100 - P_a) M_b}{100} = \text{F.M.} = 4.8$$

where:

$$P_a = \% \text{ Sand}$$

$$M_a = \text{F.M. of Sand} = 3.48$$

$$M_b = \text{F.M. of Rock} = 7.13$$

therefore,

$$P_a \times 3.48 + (100 - P_a) \times 7.13 = 4.80 \times 100$$

$$P_a = \frac{7.13 - 4.80}{3.65} = 63.9$$

from the above we find that:

$$\% \text{ Sand} = 63.9\%$$

$$\% \text{ Rock} = 36.1\%$$

therefore the proportions are:

Cement = 1
 Sand = $8 \times .639 = 5.12$
 Rock = $8 \times .361 = 2.88$

1:5.12:2.88:water to 4" slump

Similarly, mix proportions were designed for:

F.M. = 5.0, 5.2, 5.4, and 5.6

Method of Fabrication and Testing Procedure

Sufficient sand and gravel was taken from the storage bins each day for that particular day's work. A close and regular check was kept on the moisture contents of all different aggregates.

The rock was sieved down into three sizes-- 1"-3/4", 3/4"-3/8", and 3/8"-1/4". It was then recombined in definite quantities of each sieve size so that a uniform rock of constant F.M. was assured in each mix. The cement used was Standard Exshaw Portland Cement.

The mixes were mixed in the Lancaster Laboratory Mixer. All the dry aggregates were put in the machine and mixed together first. As they were mixing water was added until a slump of 4" was obtained. A slump test was run on each mix to be sure that the specified 4" slump was obtained.

From each mix the following were fabricated:

- 4 -- 6" Diameter x 12" High Cylinders
- 2 -- $3\frac{1}{2}$ " x $4\frac{1}{2}$ " x 16" Freeze-Thaw Beams

The cylinders were made in the standard fashion, namely, 3 layers, each layer being tamped 25 times with a 5/8" rod.

The beams were made in two layers, each layer tamped 25 times. The sides were then spaded with a steel trowel to insure

smooth surfaces.

Both beams and cylinders were allowed to cure in the moisture room for 24 hours, after which they were stripped of the forms and stored in water until the time for testing arrived.

One cylinder was broken in compression at 7 days after pouring, while the other three cylinders were tested at 28 days after pouring.

Both beams were put in the freeze-thaw machine after 28 days of curing. Sonic readings were taken on these beams at regular intervals to record the history of their breakdown of Modulus of Elasticity.

CONCRETE DATA--FINENESS MODULUS TESTS

(1)

Mix Proportions per Cubic Yard											(2) D.F.E. 200 Cycles		Comp. Stgth. 7Day psi	Comp. Stgth. 28Day psi
Mix No.	F.M.	Date Cast	Cement lbs.	Sand lbs.	Gravel lbs.	Water lbs.	W/C Ratio	Slump ins.	Work-ability	Mix Comment				
1DZ	4.6	Dec3	388	4.44	1720	1370	375	0.964	3½	E	V.O.	1.50	810	1620
2DZ	4.8	Dec3	396	4.51	1610	1540	350	0.881	3½	E	V.O.	1.75	1080	2040
3DZ	5.0	Dec3	400	4.56	1490	1690	334	0.836	3½	E	S.O.	1.25	1110	2300
4DZ	5.2	Dec6	405	4.62	1380	1860	306	0.755	5	V.G.	O.K.	2.50	1320	2550
5DZ	5.4	Dec6	411	4.68	1260	2040	288	0.698	4	G.	S.U.	3.25	1700	2780
6DZ	5.6	Dec15	415	4.72	1125	2190	275	0.662	4	F.	H.	22.50	1960	3480
1DY	4.6	Dec16	605	6.90	1685	1335	327	0.540	3½	E.	V.O.	10.00	2760	3840
2DY	4.8	Dec16	605	6.90	1560	1465	325	0.537	4	E.	V.O.	5.50	2720	3790
3DY	5.0	Dec20	604	6.89	1425	1590	332	0.551	3½	E.	S.O.	66.50	2720	4200
4DY	5.2	Dec16	620	7.06	1320	1780	301	0.486	3½	E.	O.K.	60.0	3240	4710
5DY	5.4	Dec15	620	7.06	1180	1920	298	0.482	3½	V.G.	O.K.	72.5	2950	4620
6DY	5.6	Dec20	631	7.21	1070	2090	270	0.428	3½	G.	S.U.	70.5	3240	5370
1EZ	4.6	Nov27	400	4.56	2210	980	328	0.820	4½	E.	V.O.	5.75	1070	1870
2EZ	4.8	Nov27	400	4.56	2040	1160	321	0.802	4	E.	V.O.	3.0	1160	2270
3EZ	5.08	Nov23	400	4.56	1795	1400	321	0.802	4	V.G.	S.O.	2.75	1250	2230

CONCRETE DATA--FINENESS MODULUS TESTS (CONT'D)

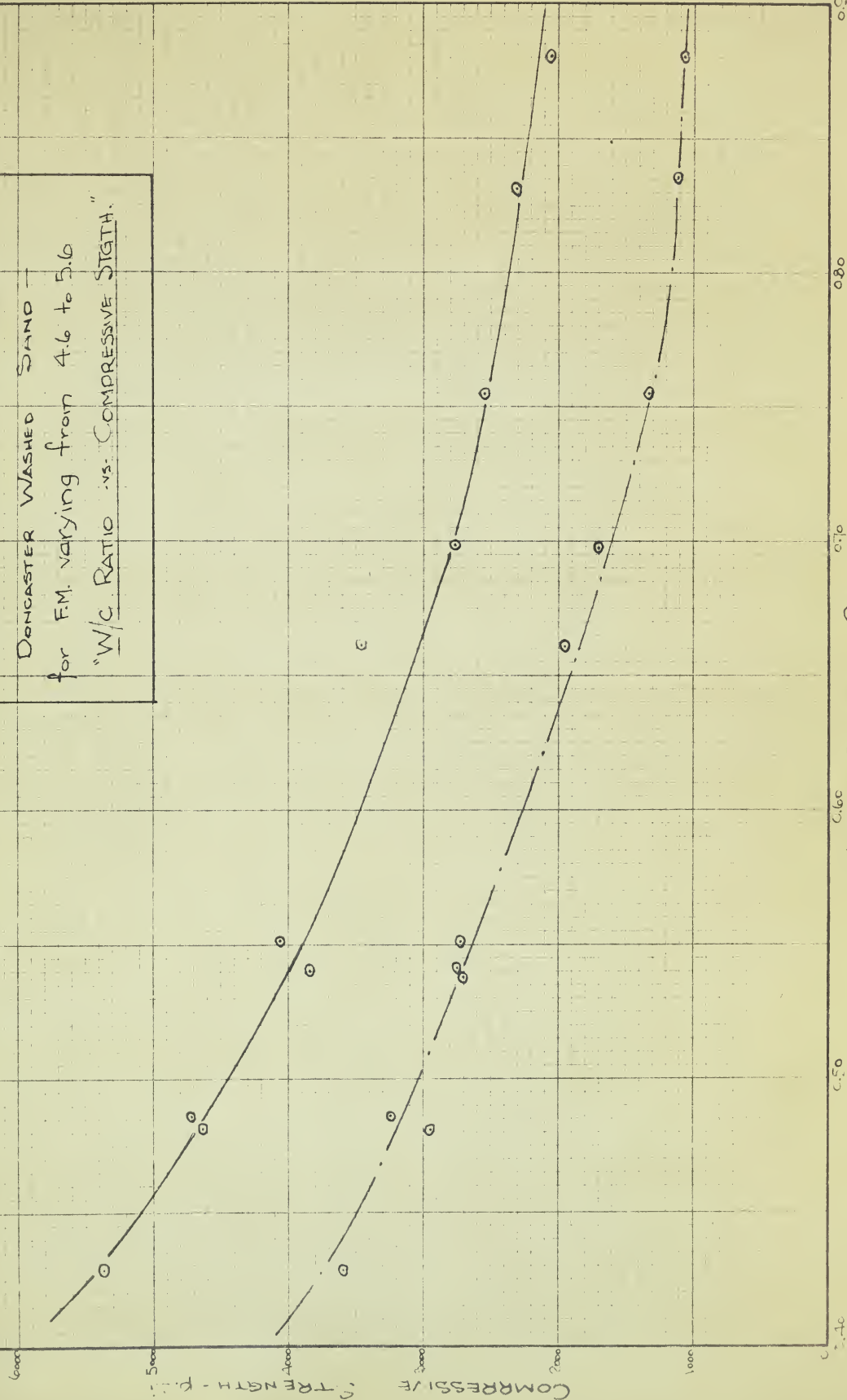
Mix No.	F.M.	Date Cast	Mix Proportions per Cubic Yard				W/C Ratio	Slump ins.	Work-ability	(2) D.F.E. 200 Cycles		(1) Comp. Stgth. 28Day psi	
			lbs.	Cement bags	Sand lbs.	Gravel lbs.	Water lbs.			Admix.	Comment	psi	psi
4EZ	5.25	Nov23	403	4.60	1665	1555	308	0.768	4½	V.G.	O.K.	1420	2720
5EZ	5.4	Nov23	406	4.64	1540	1710	300	0.737	4½	G.	S.U.	1540	2830
6EZ	5.7	Nov25	410	4.66	1225	2000	312	0.760	4½	F.	V.U.	1850	3220
1EY	4.6	Dec1	604	6.90	2085	925	328	0.543	4½	E.	V.O.	2580	4820
2EY	4.8	Dec.1	608	6.95	1975	1105	304	0.500	3½	E.	V.O.	3040	4950
3EY	5.0	Nov29	615	7.02	1810	1275	299	0.487	3½	V.G.	O.K.	2900	4630
4EY	5.2	Dec.1	615	7.02	1670	1450	286	0.464	4	V.G.	O.K.	3380	5200
5EY	5.4	Nov29	625	7.12	1490	1630	282	0.452	4	G.	S.U.	3540	5070
6EY	5.6	Nov29	626	7.14	1315	1815	278	0.444	4	F.	V.U.	3150	4810

TABLE 11

- (1) Average of 3 cylinders
- (2) The following code is used in this column:
- V.O. -- very oversanded
 - S.O. -- slightly oversanded
 - O.K. -- mix just right
 - S.U. -- slightly undersanded
 - H. -- harsh

FINENESS MODULUS TESTS

DONCASTER WASHED SAND —
for F.M. varying from 4.6 to 5.6
"W/C RATIO vs. COMPRESSIVE STGTH."



WATER - CEMENT RATIO
FIGURE 8.

FINENESS MODULUS TESTS

• ELK ISLAND SAND •

- for F.M. varying from 4.0-5.6

"W/C RATIO VS. COMPRESSIVE STRENGTH"

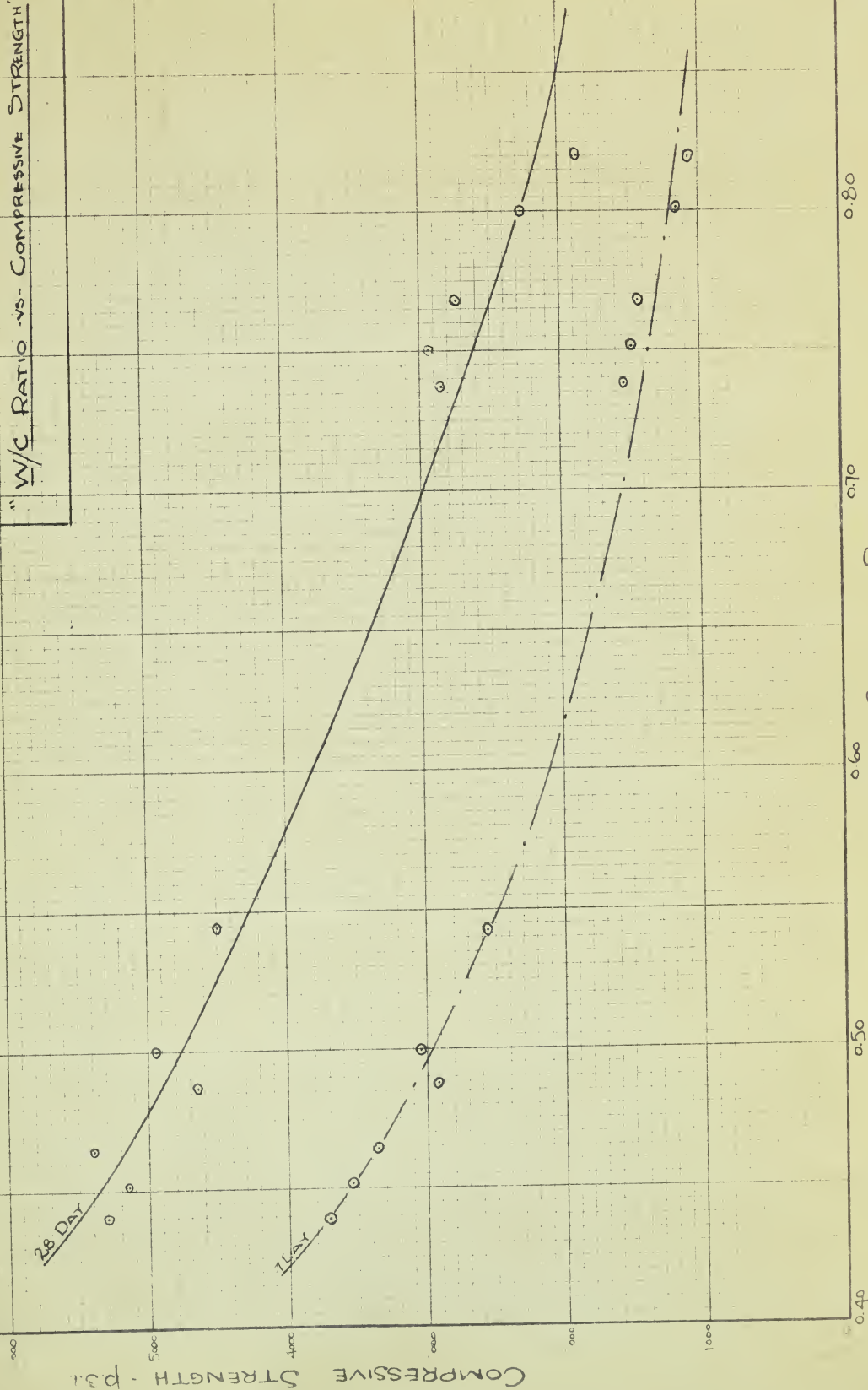
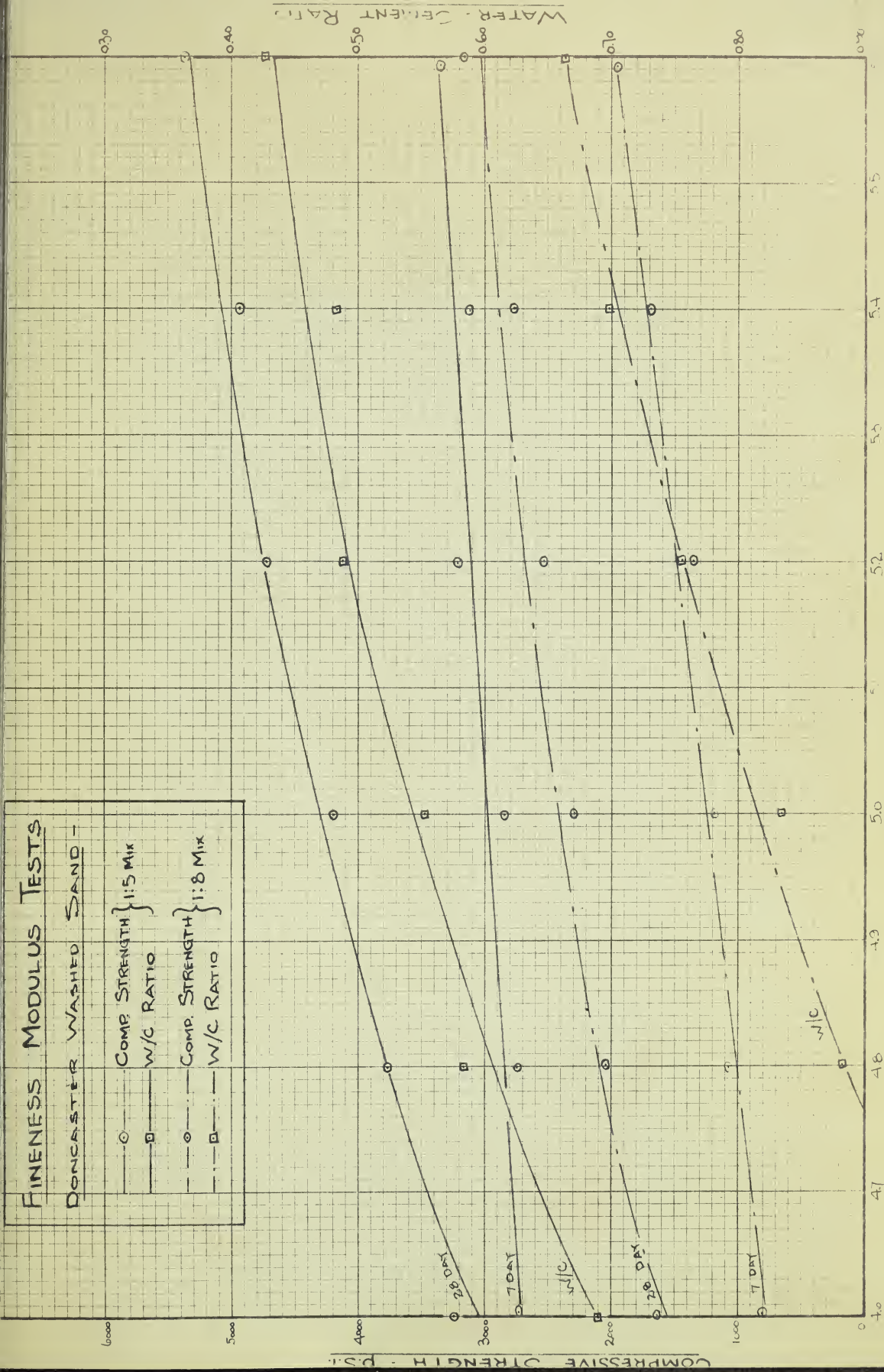
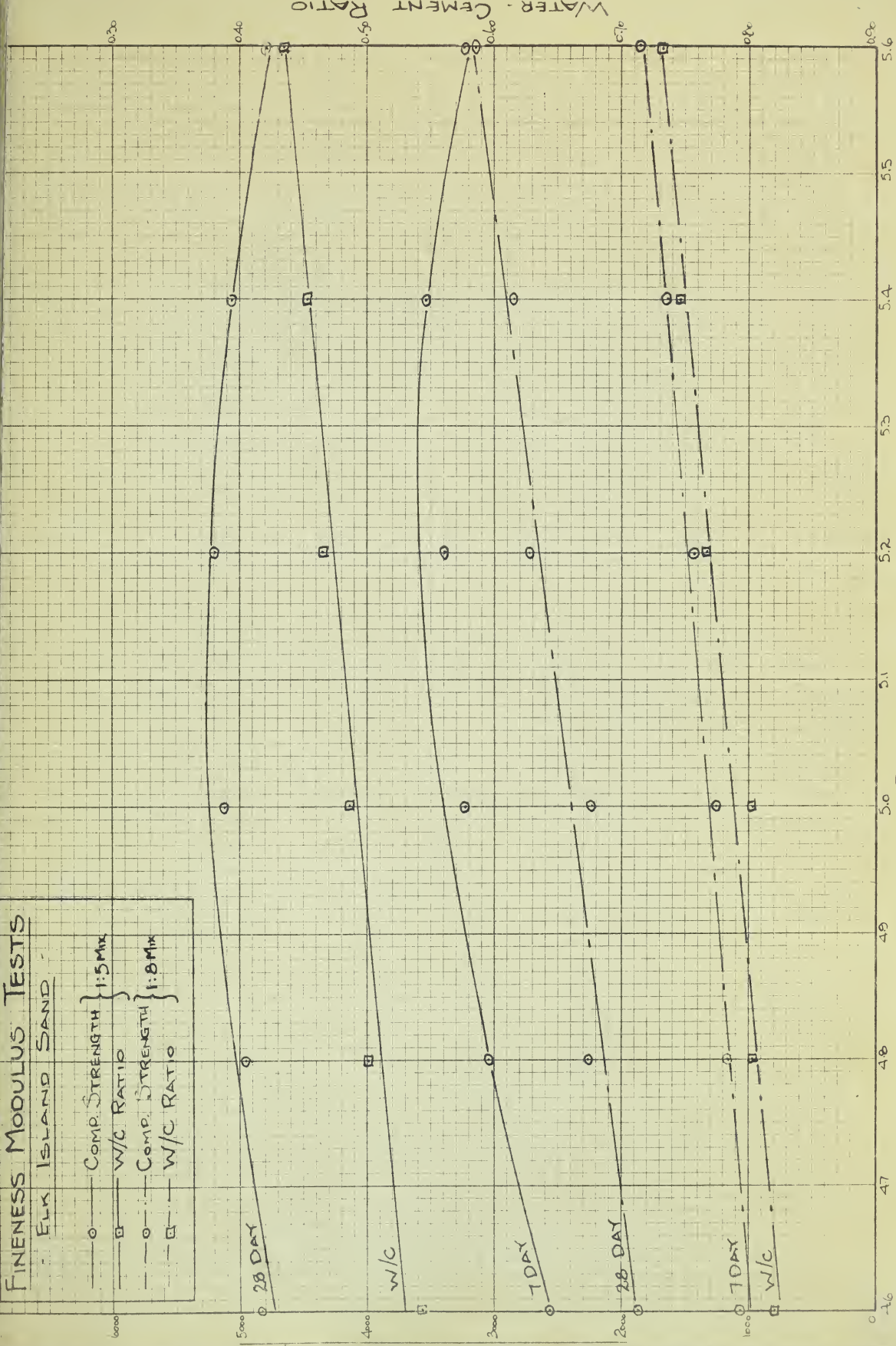


FIGURE 9.



FINESS MODULUS TESTS
ELK ISLAND SAND

—○—	COMP. STRENGTH	1:5 MIX
—□—	W/C RATIO	
—○—	COMP. STRENGTH	1:8 MIX
—□—	W/C RATIO	



FINENESS MODULUS
FIGURE 11.

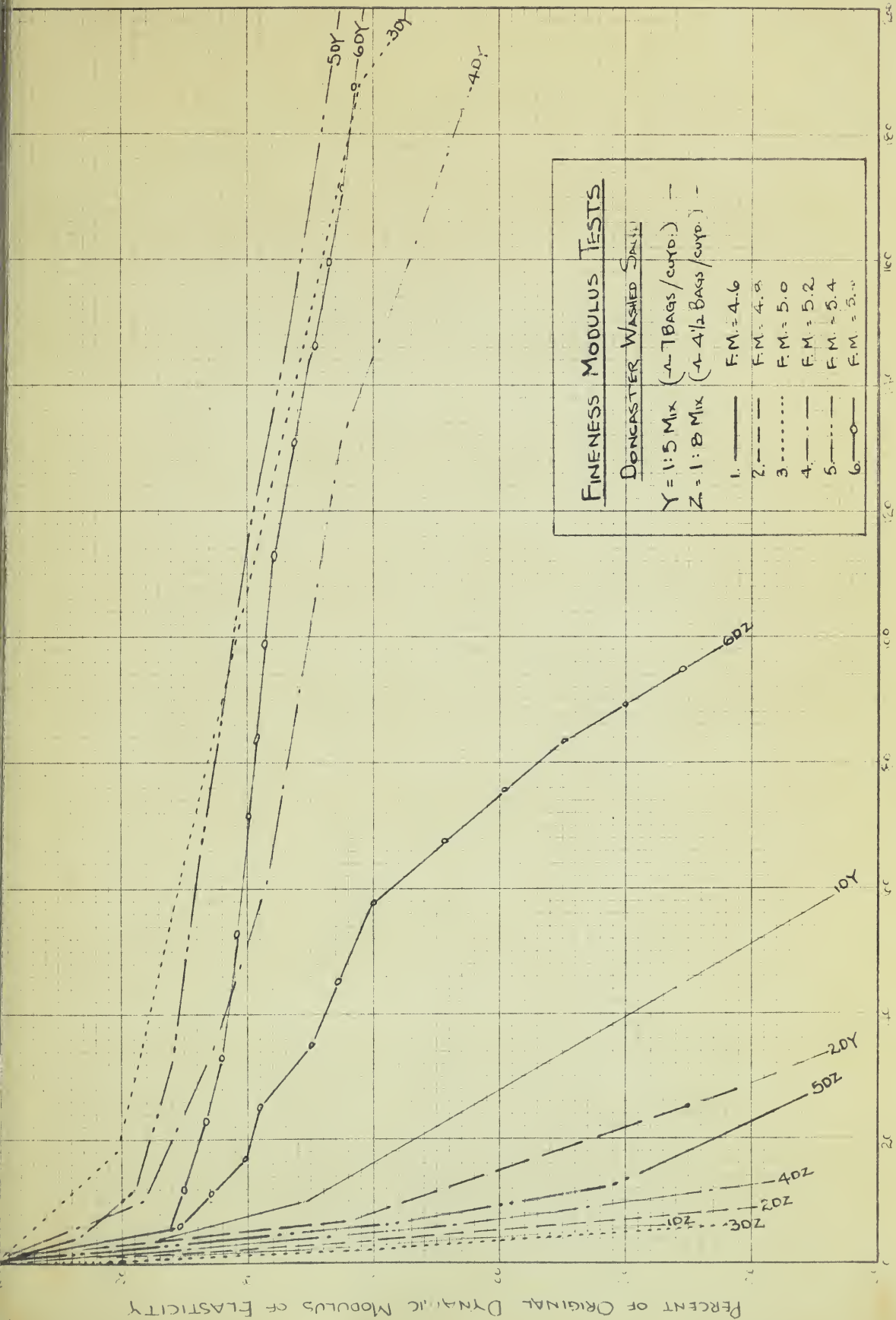


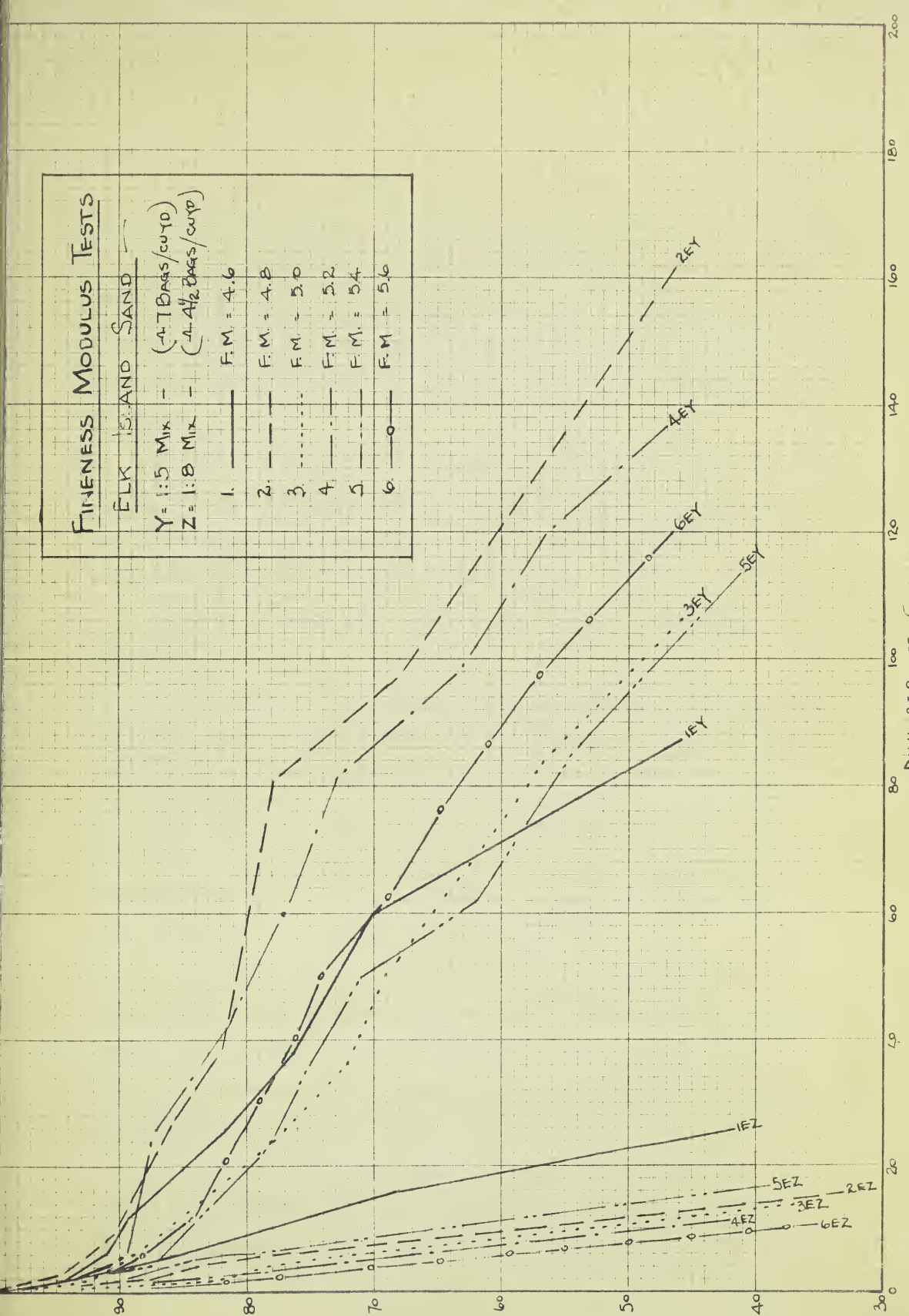
FIGURE 12.

FITNESS MODULUS TESTS

ELK 15 SAND	
Y = 1:5 Mix	(1.7 Bags/cu yd)
Z = 1:8 Mix	(1.4 1/2 Bags/cu yd)
1. —	F.M. = 4.6
2. —	F.M. = 4.8
3. - - - -	F.M. = 5.0
4. —	F.M. = 5.2
5. - - - -	F.M. = 5.4
6. —○—	F.M. = 5.6

PERCENT OF ORIGINAL DYNAMIC MODULUS OF ELASTICITY

NUMBER OF CYCLES
FIGURE 13.



Results

Instead of plotting Compressive Strength versus Fineness Modulus on a single graph, it was decided that a more complete analysis could be made by plotting both Compressive Strength and Water Cement Ratio versus Fineness Modulus on the same graph. (Figs. 10 and 11). In this way the resulting effect on compressive strength as well as the change in W/C ratio for varying F.M. could be examined simultaneously.

For the Doncaster Washed Sand for both the 1:5 and the 1:8 mixes we find that as the F.M. increases the compressive strength also increases. Even for high values of F.M. which indicate coarse mixes the compressive strength values increase. This is explained by noting that the respective W/C ratios show a corresponding decrease.

In the case of Elk Island Sand the Fineness Modulus graphs, (Fig. 11), show the same general characteristics, that is, the compressive strength curves follow according to the W/C ratio curve and do not show much variation due to decreasing F.M. The only exception to this is the curve for 1:5 mix where the compressive strength curve does indicate a decrease at higher values of F.M., even though the W/C ratio curve keeps decreasing.

In Figs. 3 and 4 the Compressive Strength versus Water Cement Ratio curves are drawn for both sands. Even though the points include the complete scatter of F.M. from 4.6 to 5.6, they show a very nice curve such as is commonly found for ordinary variations of Water Cement Ratio.

From the foregoing curves it would seem that the values of compressive strengths indicate a very normal variation consistent with the variation in W/C ratios. The effect of the changing F.M.

seems very small, if at all evident.

The durability curves, (Figs.12 and 13), are very interesting. The most striking point is the difference in durability between the 1:8 mixes and the 1:5 mixes. An increase in cement content makes for a very large increase in durability. In fact, from a $4\frac{1}{2}$ bag/yd. mix, (1 part cement to 8 parts aggregate), to a 7 bag/yd. mix, (1 part cement to 5 parts aggregate), we have an increase in durability factor at 200 cycles of more than a thousand percent.

Another interesting point is that, in general, the Doncaster Washed Sand seemed to show better durability than the Elk Island Sand. This comparison is discussed in detail in the Sand Comparison Tests.

As far as the effect of F.M. variation on durability is concerned there do not seem to be any definite conclusions from the graphs. The variations in F.M. are all mixed up in the group of curves and definitely do not show any tendency for increase or decrease in durability due to increasing F.M. Once again, this would indicate very little effect on durability caused by variations in F.M.

Summary and Conclusions

a. Summary--Two different sands were used to test the Fineness Modulus Method of design. These were Doncaster Washed and Elk Island Sands. Tests were made using two different cement factors, (1:8 and 1:5), for each sand and for overall Fineness Modulus varying from a very oversanded, rich mix, to a very undersanded, harsh mix. Every mix was tested for Compressive Strength and Durability in the accelerated freeze-thaw apparatus.

b. Conclusions

1. For lower values of F.M., (oversanded mix), a larger amount of water was required to maintain a constant slump of 4", whereas for higher values of F.M., (undersanded mix), a much less amount was required for the same 4" slump.

2. Although the strengths were lower for low values of F.M. a plot of water cement ratio versus fineness modulus indicated that this decrease in strength was almost entirely due to increase in water cement ratio.

3. No 'Optimum Fineness Modulus' was noted throughout the range of the tests.

4. A decided increase in durability was noted for those mixes containing the larger amount of cement. An increase in cement from $4\frac{1}{2}$ bags/yd. to 7 bags/yd. caused an increase in durability factor from 500 to 2000 percent.

5. The effect of variation in F.M. showed very little, if any, effect on the Durability Factor. In general there was a slight increase in durability for those mixes which were normal, (sand content not too high or too low), but this effect was so small

as to be of very little significance.

6. On the basis of the above observations, it was decided that all the future test mixes would be designed according to the American Concrete Institute Standard Method of design since no obvious increases in physical properties were noted for the 'Optimum Fineness Modulus Method' of design.

CHAPTER III

COMPARATIVE SAND AND GRAVEL TESTS

INTRODUCTION

The most important tests in the evaluation of any of the aggregates under consideration are those in which the aggregate is actually used in a concrete mix. The concrete is then put through the standard tests, namely, Compressive Strength Test, Flexural Strength Test and Durability Test in the accelerated freeze-thaw apparatus. If the concrete is properly designed, fabricated and cured, and if for a series of sand tests, say, the same gravel is used for each different concrete mix, then any variations in the behavior of the concrete can be attributed to variations in the physical properties of the sand used in that mix. In the same manner a series of gravels can be tested using the same sand.

For the mix design it was decided, on the basis of the 'Fineness Modulus Design' studies, (see Page 37), that since slight variations in fineness modulus of the sand and gravel combined had very little effect on those physical properties of the concrete to be studied, the standard A.C.I. system for design of concrete mixes⁽¹⁾ would be utilized throughout the tests as a basis for trial mixes.

(1) Journal of American Concrete Institute, November 1943.

GENERAL OUTLINE OF PROCEDURE AND TESTING

Materials

1. Aggregate--In order that all materials tested be in as uniform a condition as possible, all the sands to be tested were soaked with water for at least 2 days before testing, and all the gravel was soaked for 1 day. The samples were allowed to drain freely and moisture content determinations were made in every case just prior to mixing. At the same time a sample of each sand was sealed, to have an absorption test run on it the following day. In this manner the amount of free moisture was determined very accurately. All gravel samples used were thoroughly washed over a # 4 screen to eliminate any clay and other soluble surface coatings.

2. Cement--The cement used in every case was Standard Exshaw Portland Cement, the physical and chemical analysis of which is given on Page 17. The cement was a batch made up by thoroughly mixing several bags together to insure uniformity. The cement was stored in a tight metal drum.

3. Water--The mixing water used was normal drinking water as obtained from the Edmonton City Water Supply.

Weighings

All weighings were made on the Laboratory Scale, to the nearest ounce.

Mixing and Size of Batches

The concrete for both the sand and the gravel tests was mixed in the Laboratory Tilting Drum, 1/2 cu.ft. mixer. The materials were added in the following order:

1/2 Mixing Water
Coarse Aggregate
Fine Aggregate and Cement (thoroughly premixed by hand)
Remaining mixing Water

The concrete was mixed for 5 full minutes from the time all of the ingredients were in the mixer.

Each mix consisted of two batches of about 80 pounds each. The first batch was emptied into a steel tray and then, when the second batch was completely mixed, it was dumped on top of the first. The two batches were then thoroughly intermixed by shovel.

Slump Tests

A slump test was taken on every mix. It was attempted to keep the slump as near to 4" as possible.

Specimen Fabrication

For both the fine and the coarse aggregate evaluation tests the following specimens were fabricated:

a) Cylinders-- Standard 6" diameter by 12" high compressive strength test cylinders poured in 3 equal lifts. Each lift was tamped 25 times with a $5/8$ " diameter rod. Three cylinders were poured for each mix all of which were tested at 28 days.

b) Beams--These measured $3\frac{1}{2}$ " x $4\frac{1}{2}$ " x 16". They were poured in two layers, each layer tamped 25 times with a $5/8$ " diameter tamping rod. The sides were spaded with a steel trowel, and the top struck off smooth with a wooden float. Two beams were poured for each mix. One beam was tested for flexural strength at 28 days, the other was put in the accelerated freeze-thaw apparatus at 28 days and dynamic modulus of elasticity values were determined at regular intervals with the sonic apparatus.

Both the cylinders and beams were allowed to cure in air for the first 24 hours and then, with the forms stripped off, were cured in water at 70°F for 27 days after which they were given their respective tests.

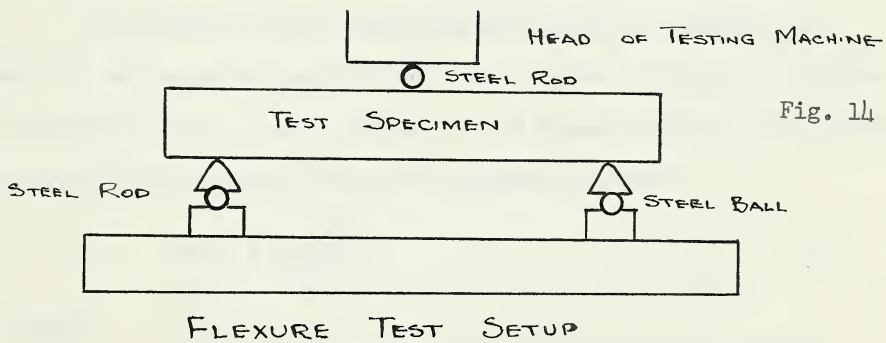
TESTING PROCEDURE

Compressive Strength Tests

The cylinders were capped with a sulphur and fire-clay mixture to insure square and level surface bearing pressures. The cross sectional diameter of each cylinder was obtained to the nearest 0.01 inches by averaging 2 diameters measured at right angles to each other near the centre of the length of the specimen. The cylinders were tested in a moist condition in the Baldwin Southwark Emery-Tate Testing Machine. The load was applied at a constant rate of 50 p.s.i. per second.

Flexural Strength Tests

The beams were tested in a moist condition. Centre-point loading was applied with the beam supported at each end. The clear span of the beam was 12 inches, centre to centre.



The load was applied by the Baldwin Southwark Emery-Tate Testing Machine. The modulus of rupture was computed from the following formula:

$$R = \frac{My}{I}$$

where,

$$\begin{aligned} M &= \text{Maximum bending moment due to applied load} \\ y &= \frac{1}{2} \text{ Depth of the specimen} \\ I &= \text{Moment of Inertia about Neutral Axis} = \frac{bd^3}{12} \end{aligned}$$

Durability Tests

The beams were first weighed in air and then in water to determine their volume. An initial sonic reading was taken in the sonic apparatus, (see Page 3). The beams were then put in individual sheet metal containers which, in turn, were filled with water and placed in the testing tank. The beam went through a cycle of freezing and thawing every two hours. Sonic readings were taken at approximately 0, 2, 5, 10, 20, 50, 100, 150 and 200 cycles. Dynamic Modulus of Elasticity of the beam decreased to less than 50% of the original E or when the beam had completed 200 continuous cycles. The values for Dynamic Modulus of Elasticity were computed from the relationship given on Page 1 .

The history of the resulting breakdown or decrease in Dynamic E was plotted against the total number of cycles. A value for Durability Factor, (DFE), based on the Dynamic Modulus of Elasticity was computed for each mix using the following formula:

$$DFE = \frac{PN^{(1)}}{M}$$

where,

$$DFE = \text{Durability Factor in percent of dynamic E at zero cycles.}$$

- (1) 'Laboratory Studies of Concrete Containing Air-Entraining Admixtures'--Charles E. Wuerpel, Proceedings of the American Concrete Institute, Volume 42, 1946.

- P = Relative E of 50% or greater at time
of test based on E at zero cycles.
- N = Number of cycles at which P reaches 50%
or the ultimate number of cycles of the
test prior to completion of the test.
- M = Ultimate number of cycles of the test = 200 cycles

SAND EVALUATION TESTS

The following sands were investigated:

Dewinton Sand	}	Calgary Area
Clarke's Sand (Cochrane)		
A mixture of $\frac{1}{2}$ River and $\frac{1}{2}$ Dewinton		
Doncaster Washed Sand	}	Edmonton Area
Doncaster Pit Run Sand		
Elk Island Sand		

The River Sand was too coarse to use alone in a concrete mix so a mixture of $\frac{1}{2}$ River Sand and $\frac{1}{2}$ Dewinton Sand was tested instead.

Each sand was incorporated into a mix using the standard A.C.I. method of design. The rock which was used for all the sand tests was O.K. Construction rock. This rock was used because it was readily available and could easily be washed clean, sieved down into 3 component-size fractions and recombined. The rock was recombined in the following amounts for each test:

1" - $\frac{3}{4}$ "	--	30%
$\frac{3}{4}$ " - $\frac{3}{8}$ "	--	53%
$\frac{3}{8}$ " - #4	--	17%

Two different mixes were designed and run for each sand, one mix using 5 bags of cement per yard of concrete and another mix using $6\frac{1}{2}$ bags of cement per yard of concrete. Each mix was repeated once making a total of 24 mixes.

Sample Mix Design

a) Sand-- Doncaster Washed Sand

$$\text{F.M.} = 2.63$$

$$\text{Bulk Specific Gravity (Sat. surf. dry Cond.)} = 2.61$$

b) Rock-- O.K. Construction Rock - 1" maximum size

$$\text{F.M.} = 7.13$$

$$\text{Bulk Specific Gravity} = 2.61$$

c) Cement-- Standard Exshaw Portland Cement

$$\text{Specific Gravity} = 3.13$$

Design for 5 bags/cu.yd., and 4" slump

$$\text{Cement content} -- \frac{5 \times 87.5}{62.4 \times 3.13} \text{ ----- } 2.24 \text{ ft}^2$$

$$\text{Water} = \frac{310\#}{62.4} \text{ ----- } 4.97 \text{ ft}^2$$

$$\text{Therefore, total absolute volume of cement and water} = 7.21 \text{ ft}^2$$

$$\text{Volume of aggregate} = 27.00 - 7.21 = 19.79 \text{ ft}^2$$

$$\% \text{ Sand} = 41 + (\text{correction for W/C ratio} = 3) + \text{correction (for F.M.} = 1)$$

$$= 41 + 3 + 1 = 45\%$$

$$\text{Volume of Sand} = 0.45 \times 19.79 = 8.90$$

$$\text{Volume of Rock} = 0.55 \times 19.79 = 10.89$$

$$\text{Weight of Sand} = 8.90 \times 2.61 \times 62.4 = 1450 \text{ lbs.}$$

$$\text{Weight of Rock} = 10.89 \times 2.61 \times 62.4 = 1770 \text{ lbs.}$$

The quantities of materials used per cubic yard of concrete are:

$$\text{Cement} = 437.5 \text{ lbs.}$$

$$\text{Water} = 310 \text{ lbs.}$$

$$\text{Sand} = 1450 \text{ lbs.}$$

$$\text{Rock} = 1770 \text{ lbs.}$$

A table showing the net weights of materials used in each mix is given on Page 48 .

TABLE 12

SCHEDULE OF CYLINDERS AND BEAMS

Code	Sand	Cement Content
S5DW	Doncaster Washed Sand	5 bags per yard
S6DW	Doncaster Washed Sand	$6\frac{1}{2}$ bags per yard
S5DP	Doncaster Pit Run Sand	5 bags per yard
S6DP	Doncaster Pit Run Sand	$6\frac{1}{2}$ bags per yard
S5E	Elk Island Sand	5 bags per yard
S6E	Elk Island Sand	$6\frac{1}{2}$ bags per yard
S5De	Dewinton Sand	5 bags per yard
S6De	Dewinton Sand	$6\frac{1}{2}$ bags per yard
S5C	Clarke's Sand	5 bags per yard
S6C	Clarke's Sand	$6\frac{1}{2}$ bags per yard
S5R + De	Mixture of $\frac{1}{2}$ River and $\frac{1}{2}$ Dewinton	5 bags per yard
S6R + De	Mixture of $\frac{1}{2}$ River and $\frac{1}{2}$ Dewinton	$6\frac{1}{2}$ bags per yard

Note: A prefix of '2' in front of each code signifies the second run of the same mix. Second runs were never performed on the same day as the original run.

CONCRETE DATA--COMPARATIVE SAND TESTS

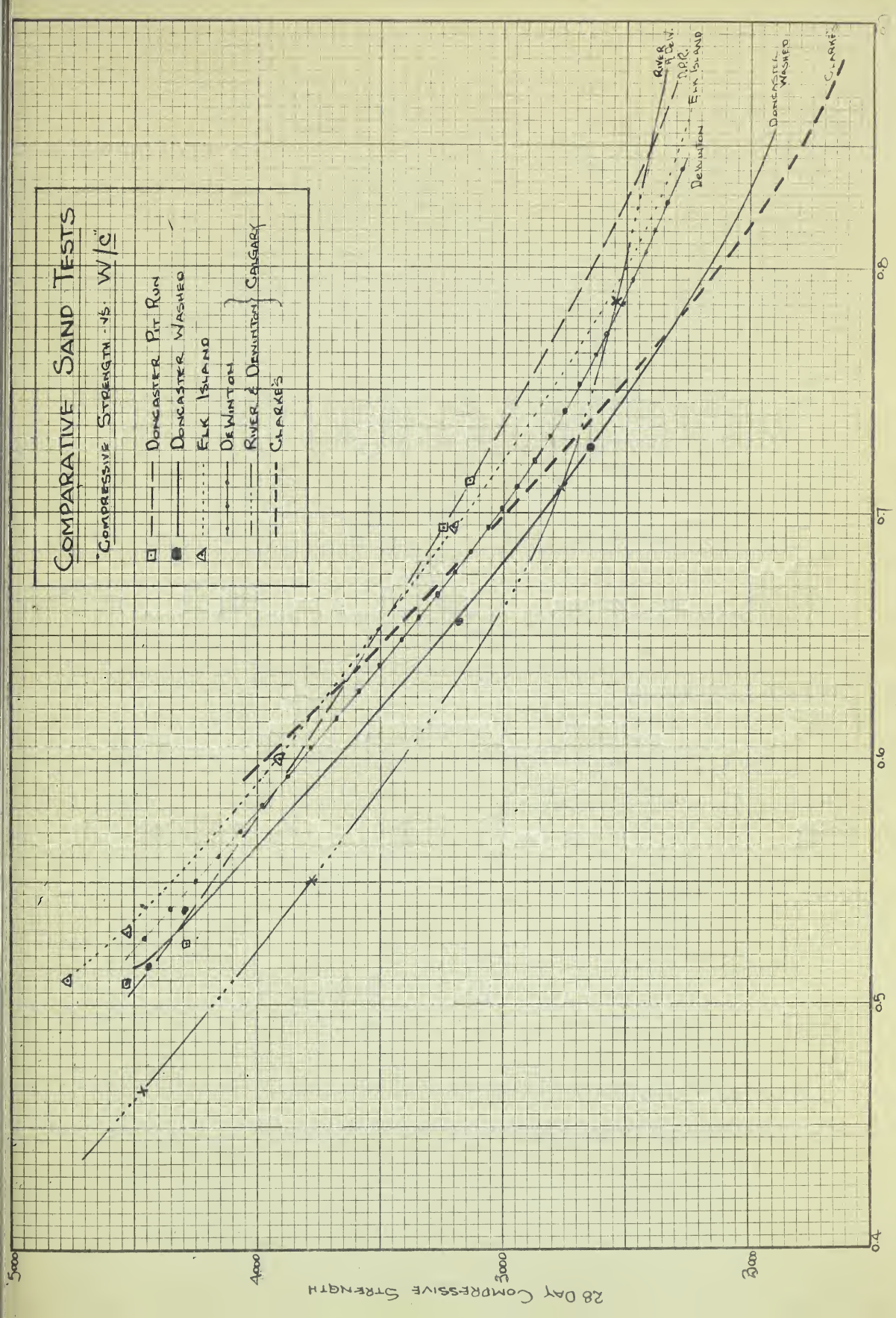
Mix No.	Date Cast	Mix Proportions per Cubic Yard					W/C Ratio	Slump ins.	D.F.E. 200 Cycles	Work-ability	(1) Comp. Stgth. 28Day psi		Flex. Stgth. 28Day psi
		Cement lbs.	Sand lbs.	Gravel lbs.	Water lbs.	Admix.					psi	psi	
2S5C	Jan. 14	430	1250	1840	343	none	0.798	4	1.25	V.G.	2140	450	
5C	Jan. 12	545	1125	1850	354	none	0.654	4½	0.75	E	3470	525	
2S6C	Jan. 14	554	1080	1920	344	none	0.620	4½	3.50	V.G.	3740	585	
S5DP	Jan. 24	435	1415	1770	310	none	0.713	3½	9.0	V.G.	3140	565	
2S5DP	Jan. 26	440	1400	1805	305	none	0.694	3½	39.5	V.G.	3260	587	
S6DP	Jan. 24	570	1290	1805	303	none	0.530	3½	66.0	E	4090	576	
2S6DP	Jan. 26	573	1270	1845	292	none	0.510	4	65.4	V.G.	4690	652	
S5DW	Jan. 13	442	1435	1810	320	none	0.726	4	10.5	V.G.	2650	515	
2S5DW	Jan. 17	435	1390	1785	288	none	0.662	4	33.0	--	3170	520	
S6DW	Jan. 13	572	1275	1840	295	none	0.516	4	45.5	E	4430	762	
2S6DW	Jan. 14	570	1260	1830	306	none	0.540	4½	45.5	V.G.	4320	616	
S5E	Jan. 19	446	1590	1700	267	none	0.600	3½	23.0	G.	3380	678	
2S5E	Jan. 24	438	1565	1640	303	none	0.694	3½	11.2	V.G.	3290	630	
S6E	Jan. 19	576	1480	1700	271	none	0.468	3¾	66.6	V.G.	4720	804	
2S6E	Jan. 26	568	1440	1660	302	none	0.530	4	33.0	--	4540	706	

CONCRETE DATA--COMPARATIVE SAND TESTS--(CONT'D)

Mix Proportions per Cubic Yard										(1)			
Mix No.	Date Cast	Cement lbs.	Cement bags	Sand lbs.	Gravel lbs.	Water lbs.	Admix.	W/C Ratio	Slump ins.	D.F.E. 200 Cycles	Work-ability	Comp. Stgth. 28Day psi	Flex. Stgth. 28Day psi
S5De	Jan.11	427	4.88	1340	1790	325	none	0.760	3	0.75	V.G.	2730	516
2S5De	Jan.13	430	4.91	1345	1800	315	none	0.732	4	1.0	--	2760	534
S6De	Jan.12	556	6.36	1230	1830	312	none	0.562	4½	6.5	F	4130	585
2S6De	Jan.17	570	6.50	1145	2110	308	none	0.541	5	25.2	F	4310	575
S5R+De	Jan.11	432	4.93	1415	1755	306	none	0.710	3¾	0.75	V.G.	2760	--
2S5R+De	Jan.19	435	4.96	1295	1780	343	none	0.788	4	1.50	F	2560	510
S6R+De	Jan.12	567	6.46	1360	1700	310	none	0.550	4	28.8	V.G.	3770	645
2S6R+De	Jan.17	588	6.71	1365	1765	272	none	0.464	4½	36.2	F	4490	660

TABLE 13

(1) Average of 3 cylinders.



Water - Cement Ratio
FIGURE 15.

COMPARATIVE SAND TESTS

"FLEXURAL STRENGTH" vs. $\frac{W}{C}$

○	DONCASTER PIT RUN
□	DONCASTER WASHED
⊕	ELK ISLAND
⊗	DEWINTON
△	RIVER + DEWINTON
×	CLARKE'S

} CALGARY

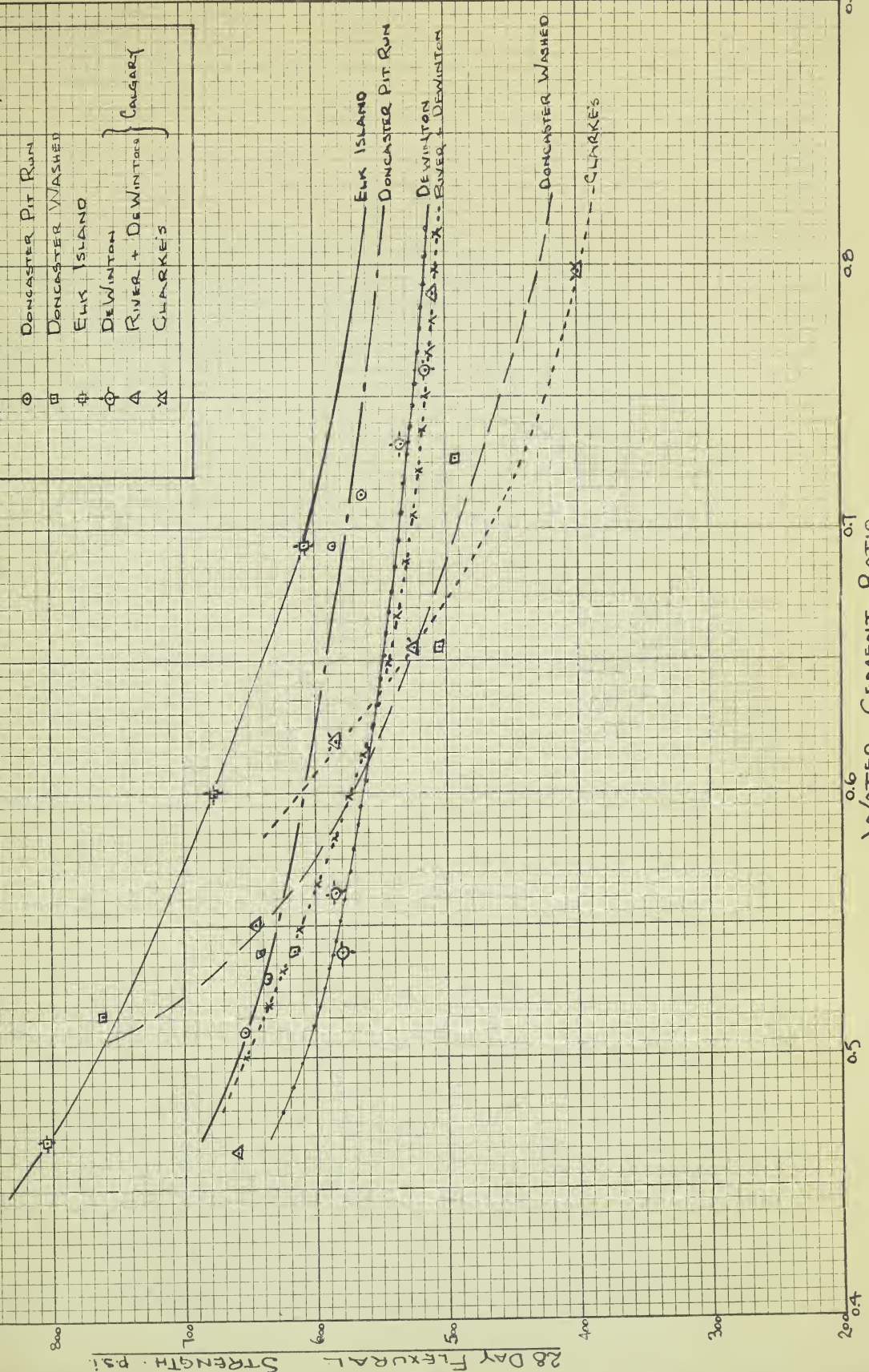


FIGURE 16.

COMPARATIVE SAND TESTS

"DURABILITY EVALUATION"

in

FREEZE-THAW APPARATUS

Percent of Original Dynamic Modulus of Elasticity

0%

1%

2%

3%

4%

5%

6%

7%

8%

9%

10%

11%

12%

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14%

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COMPARATIVE SAND TESTS
DURABILITY EVALUATION ~
in
FREEZE-THAW APPARATUS
Run No. 2

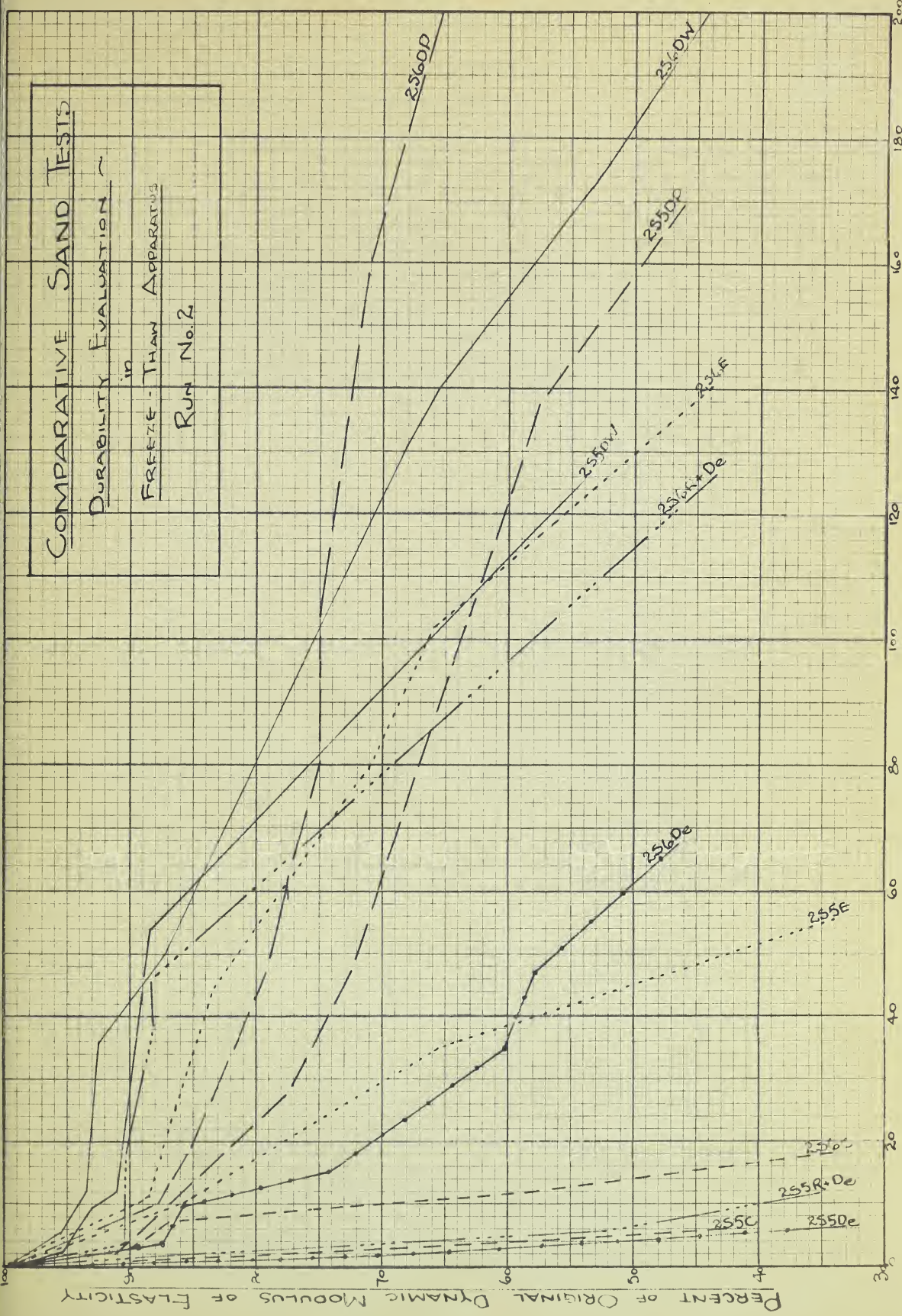
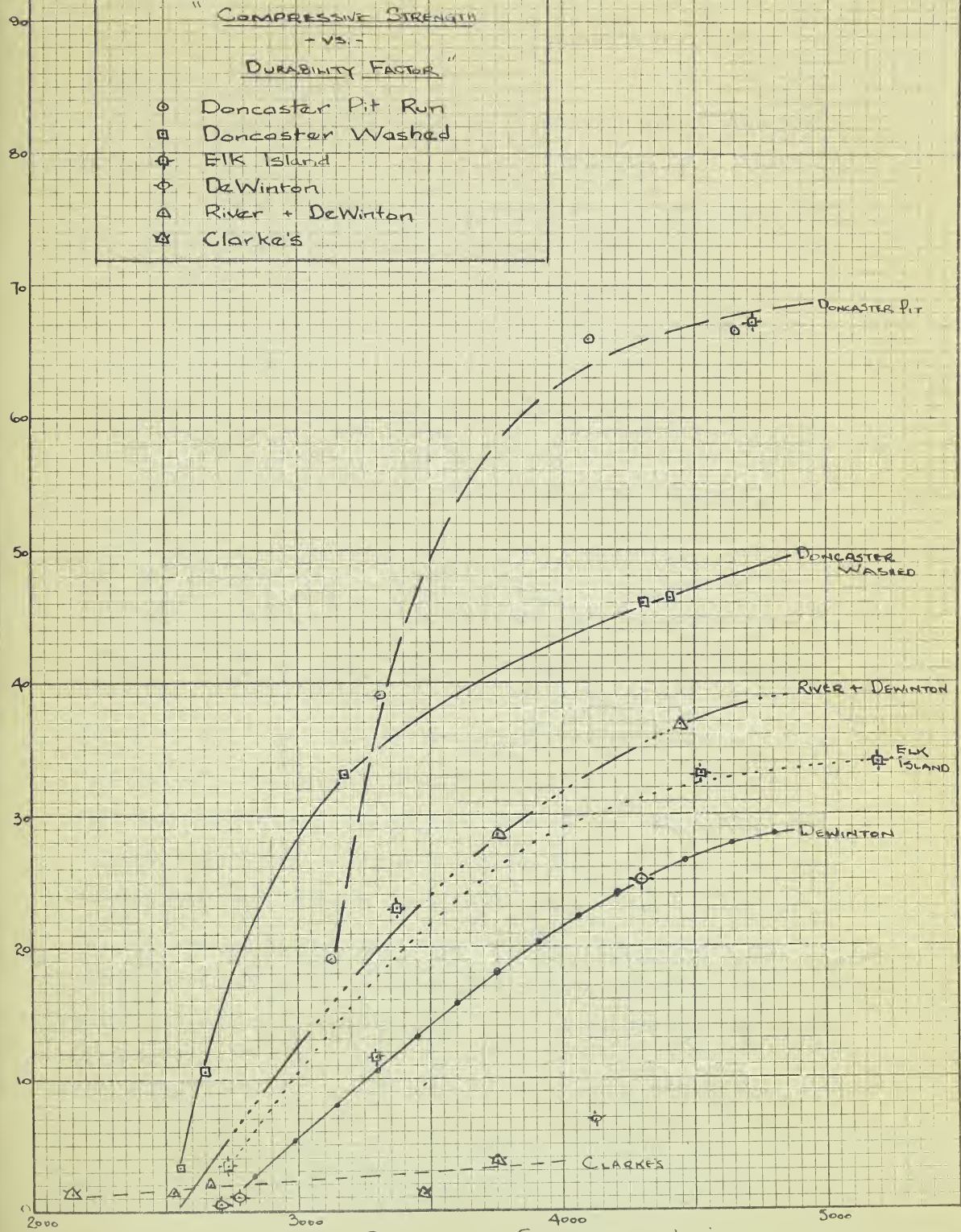


FIGURE 18

COMPARATIVE SAND TESTS

" COMPRESSIVE STRENGTH
- VS. -
DURABILITY FACTOR "

- Doncaster Pit Run
- Doncaster Washed
- ⊕ Elk Island
- ⊙ DeWinton
- △ River + DeWinton
- ☆ Clarke's



28 DAY COMPRESSIVE STRENGTH - p.s.i.

FIGURE 19.

RESULTS OF SAND EVALUATION TESTS

Compressive Strength Tests

A plot of 28 day, compressive strength versus W/C ratio is shown in Fig. 15 .

Most of the points fell very nicely along the typical "W/C Ratio versus Compressive Strength" curve. In each case a 'best fit' line was chosen from all of the points for each sand tested.

From the curves it is seen that, for values of W/C ratio greater than about 0.65, concrete containing Doncaster Pit Run Sand shows the best compressive strengths with Elk Island Sand being only slightly below. In this high range of W/C ratios Clarke's Sand is the poorest of all, falling very rapidly for slight increases in W/C ratio.

For lower values of W/C ratio, (< 0.65), the concrete containing $\frac{1}{2}$ River and $\frac{1}{2}$ Dewinton Sand drops considerably in compressive strength. On the other hand Clarke's Sand picks up considerably and shows increasingly better compressive strength values for lower W/C. The Doncaster Washed Sand is, in general, much lower than the other sands. This is particularly strange in view of the fact that the Doncaster Pit Run Sand shows up very well in this plot. This may be explained by the fact that the Doncaster Washed Sand was brought into the laboratory early in the summer while the Doncaster Pit Run Sand was brought in late in the fall. Thus, because the batches were different, some variations might be expected. It has been past experience also, to note large variations in Doncaster Sand from batch to batch.

Flexural Strength Tests

A plot of 28 day Flexural Strength versus W/C ratio is shown in Fig. 16 .

Elk Island Sand shows by far the most favorable flexural strength, being about 15 to 20 per cent higher than any other sand. Doncaster Pit Run Sand is fairly high on the graph, but fails to show proper increases for decreasing W/C ratio.

In this plot, as in the plot of compressive strength versus W/C ratio, both Clarke's Sand and Doncaster Washed Sand show very low strengths for high values of W/C but pick up considerably for lower values of W/C.

Both Dewinton Sand and the $\frac{1}{2}$ River and $\frac{1}{2}$ Dewinton mixture show medium good flexural strengths for high values of W/C, but indicate poor strengths for lower values. There does not seem to be much difference between either of these mixes.

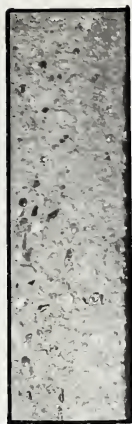
Durability Tests

Two series of beams were tested in the freeze-thaw apparatus. The first series consisted of beams made from the different sands to be tested using 5 bags of cement per yard of concrete and also using $6\frac{1}{2}$ bags. The plot of 'Percent Original Dynamic Modulus of Elasticity versus Number of Cycles' for this run, No. 1, is shown in Fig. 17 . The whole series of mixes was repeated, (on different days), giving a second set of check tests. The results of run No. 2 are plotted in Fig. 18 . In both cases testing was continued until E had decreased to 50% of the original or until 200 cycles had been run.

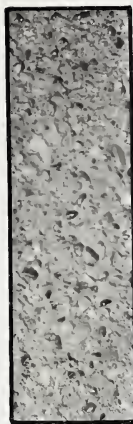
The two sets of results are in fairly close agreement, with a few exceptions.



0 CYCLES



10 CYCLES



20 CYCLES



40 CYCLES



75 CYCLES



100 CYCLES



130 CYCLES



180 CYCLES

FIGURE 20 . TYPICAL FREEZE - THAW BREAKDOWN

In run No. 1 the $6\frac{1}{2}$ bag mix of Elk Island Sand shows much greater durability than the same mix in run No. 2. This is partly explained by the fact that a breakdown for several days occurred during testing of run No. 1, giving the beam a chance to 'recuperate'.⁽¹⁾

The 5 bag mixes of Doncaster Washed and Doncaster Pit Run Sands show much less durability in run No. 1 than in run No. 2. There does not seem to be any feasible explanation for this.

With the exception of the above the results of both runs check fairly closely.

The first interesting point to note is that the cement factor has a very decided influence on the durability. For nearly all of the sands tested the $6\frac{1}{2}$ bag mixes showed amazing increases in durability over the 5 bag mixes. From the values of Durability Factor, (DFE), shown in Table 13 it can be seen that increases of several hundred per cent and more occur.

The most durable sand of those tested was Doncaster Pit Run. The Doncaster Washed Sand was next, having also a very high durability factor. Elk Island Sand which showed such exceptionally good compressive strength results, was not as good in durability. Except for one beam which stood up very well, all of the beams tested in the sand tests, and those tested in the Fineness Modulus Tests, showed much lower values of DFE than Doncaster Washed Sand. This would indicate that Elk Island Sand, though having excellent strength properties, does not show very good durability. This may be due to the thermal properties of the sand, (increased expansion and contraction), or it may be due

(1) If beams are allowed to rest for a lengthy time between cycles of freezing and thawing, they tend to regain some of their 'Modulus of Elasticity'. This phenomenon is called 'recuperating'.

to some other effect, such as the internal void structure of the grains. In many cases a low durability factor would be sufficient cause to reject the sand.

All of the sands from the Calgary area show particularly low durability properties. Clarke's Sand is the worst in this respect, showing a DFE at 200 cycles of about 0.75 for 5 bag mixes and about 1.50 for $6\frac{1}{2}$ bag mixes.

The best mix of the Calgary Sands from the durability standpoint is the mixture of $\frac{1}{2}$ River and $\frac{1}{2}$ Dewinton Sands. This mix, though showing very low durability for the 5 bag mix, indicates a very considerable increase for the $6\frac{1}{2}$ bag mix.

The Dewinton sand shows some increase in durability for the $6\frac{1}{2}$ bag mix, but this is very little compared to the other sands.

A plot of Durability Factor versus 28 day Compressive Strength is shown in Fig.19 . This gives a very good illustration of the durability of all of the different sands as compared to their compressive strength. Once again, the order in decreasing durability of the different sands is seen. It is interesting to note that a very definite break occurs in all the curves at around 3500 p.s.i. For compressive strengths less than this value the durability factor drops very rapidly, whereas, for compressive strengths higher than this, the rate of increase in durability factor decreases rapidly. This bears out the fact that, for the sake of increased durability, it is well worthwhile to design mixes for a nominal strength of around 3500 p.s.i.

ROCK EVALUATION TESTS

The following gravels were investigated:

Alberta Transit Mix Rock	--	Calgary area
O.K. Construction Rock	} --	Edmonton area
Alberta Concrete Products Rock		
Bennett and White Rock		

Each rock was incorporated into a standard A.C.I. mix design. Doncaster Pit Run Sand was used for each mix.

The sand was kept pre-soaked and, for every mix at the time of mixing, a moisture content was run on the sand and a sample was also taken and sealed to have an absorption test run the following day. From this information the free surface moisture could be calculated accurately for each mix.

Each rock was pre-soaked for 24 hours before mixing and allowed to drain freely for about 1 hour before mixing. A moisture content was run on a sample of rock just prior to mixing, and from the 24 hour absorption value of the rock, the amount of free moisture could be accurately determined.

Two different mixes were designed and run for each rock, one mix using 5 bags cement per yard of concrete and the other mix using $6\frac{1}{2}$ bags. Each mix was repeated once making a total of 16 mixes.

Table 13 shows the materials used in each mix, together with the slump, strengths and durability factors obtained.

SCHEDULE OF CYLINDERS AND BEAMS

Code	Rock	Cement Content
R5ATM	Alberta Transit Mix	5 bags per yard
R6ATM	Alberta Transit Mix	$6\frac{1}{2}$ bags per yard
R5OK	O.K. Construction	5 bags per yard
R6OK	O.K. Construction	$6\frac{1}{2}$ bags per yard
R5ACP	Alberta Concrete Products	5 bags per yard
R6ACP	Alberta Concrete Products	$6\frac{1}{2}$ bags per yard
R5BW	Bennett and White	5 bags per yard
R6BW	Bennett and White	$6\frac{1}{2}$ bags per yard

TABLE 14

Note: A prefix of '2' in front of each code signifies the second run of the same mix. The second run of any mix was never performed on the same day as the original run of that mix.

CONCRETE DATA--COMPARATIVE ROCK TESTS

(1) (2)

Mix No.	Date Cast	Mix Proportions/cu.yd.				W/C Ratio	Slump ins.	D.F.E 200 Cycles	Work-ability	Comp. Flex. Stgth. 28Day	
		Cement lbs.	Sand lbs.	Gravel lbs.	Water lbs.					psi	psi
R5ATM	Feb.2	438	1490	1720	324	0.740	4½	13.5	E	3260	520
2R5ATM	Feb.9	445	1440	1820	308	0.686	3½	24.0	V.G.	3200	495
R6ATM	Feb.4	590	1480	1690	291	0.493	5	30.5	E	4670	660
2R6ATM	Feb.7	592	1415	1740	305	0.514	3½	34.0	E	4410	695
R5ACP	Feb.2	446	1450	1810	282	0.634	4½	32.5	E	3210	506
2R5ACP	Feb.7	443	1440	1780	300	0.680	4½	28.0	E	2810	455
R6ACP	Feb.4	580	1320	1840	282	0.486	5	43.5	V.G.	4770	622
2R6ACP	Feb.9	581	1320	1830	285	0.492	4	39.5	E	4280	586
R5BW	Feb.7	445	1510	1690	306	0.690	4½	24.0	V.G.	2700	410
2R5BW	Feb.9	446	1480	1730	302	0.675	4½	23.0	E	2850	472
R6BW	Feb.2	574	1390	1710	304	0.530	4½	50.0	E	4070	585
2R6BW	Feb.4	576	1360	1770	298	0.518	4	35.5	V.G.	3750	--
R5OK	Jan.24	435	1415	1770	310	0.713	3½	9.0	V.G.	3140	565
2R5OK	Jan.26	440	1400	1805	305	0.694	3½	18.0	V.G.	3260	587
R6OK	Jan.24	570	1290	1805	303	0.530	3½	66.0	E	4090	576
2R6OK	Jan.26	573	1270	1845	292	0.510	4	65.0	V.G.	4690	652

TABLE 15

(1) Average of 3 cylinders.
(2) One beam tested.

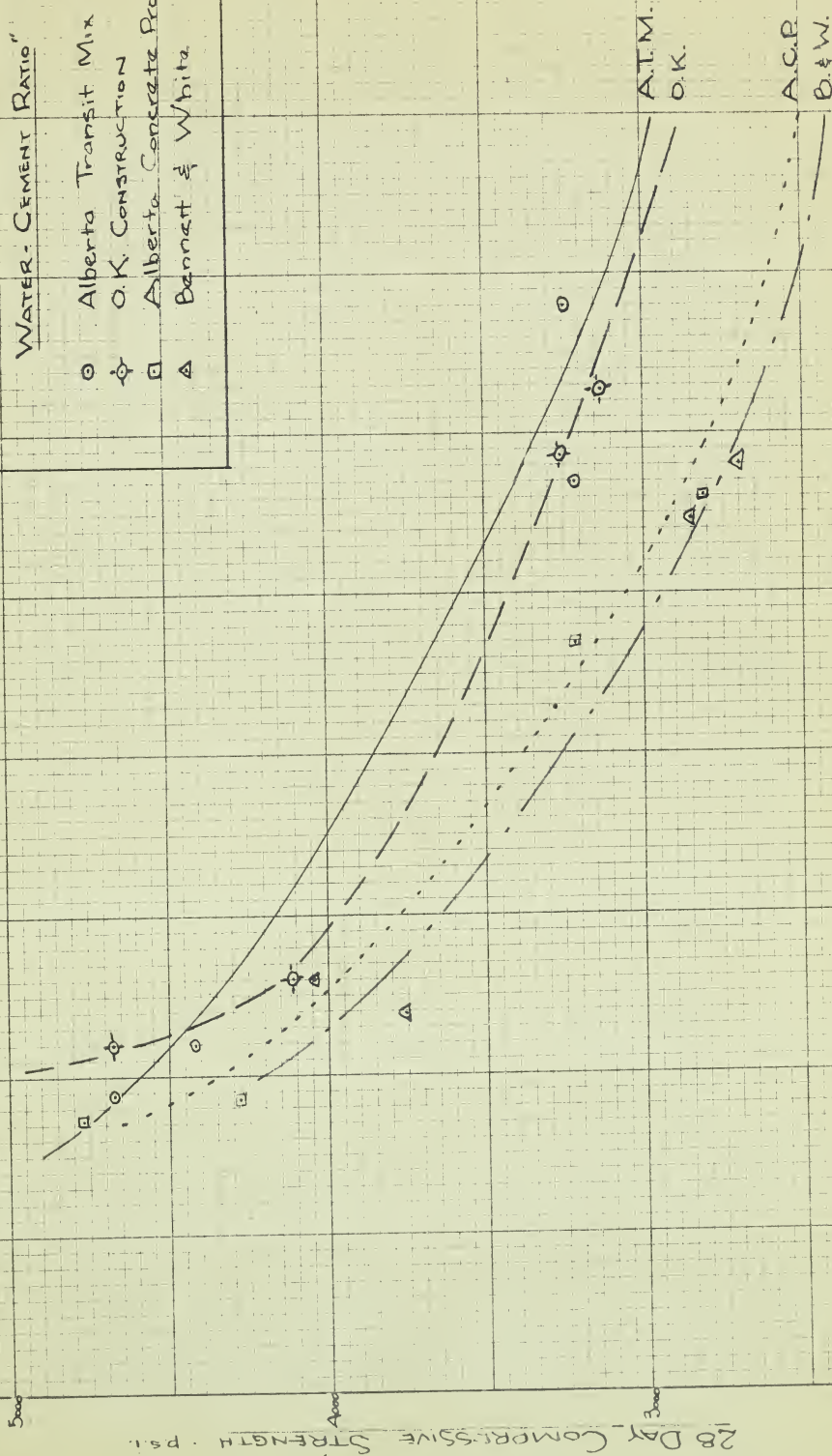
COMPARATIVE ROCK TESTS

"COMPRESSIVE STRENGTH"

- V.S. -

"WATER - CEMENT RATIO"

- Alberta Transit Mix
- ⊕ O.K. Construction
- Alberta Concrete Products
- △ Bennett & White



0.4

0.5

0.6

0.7

0.8

0.9

FIGURE 21

WATER - CEMENT RATIO

0.4

0.5

0.6

0.7

0.8

0.9

0.4

0.5

0.6

0.7

0.8

0.9

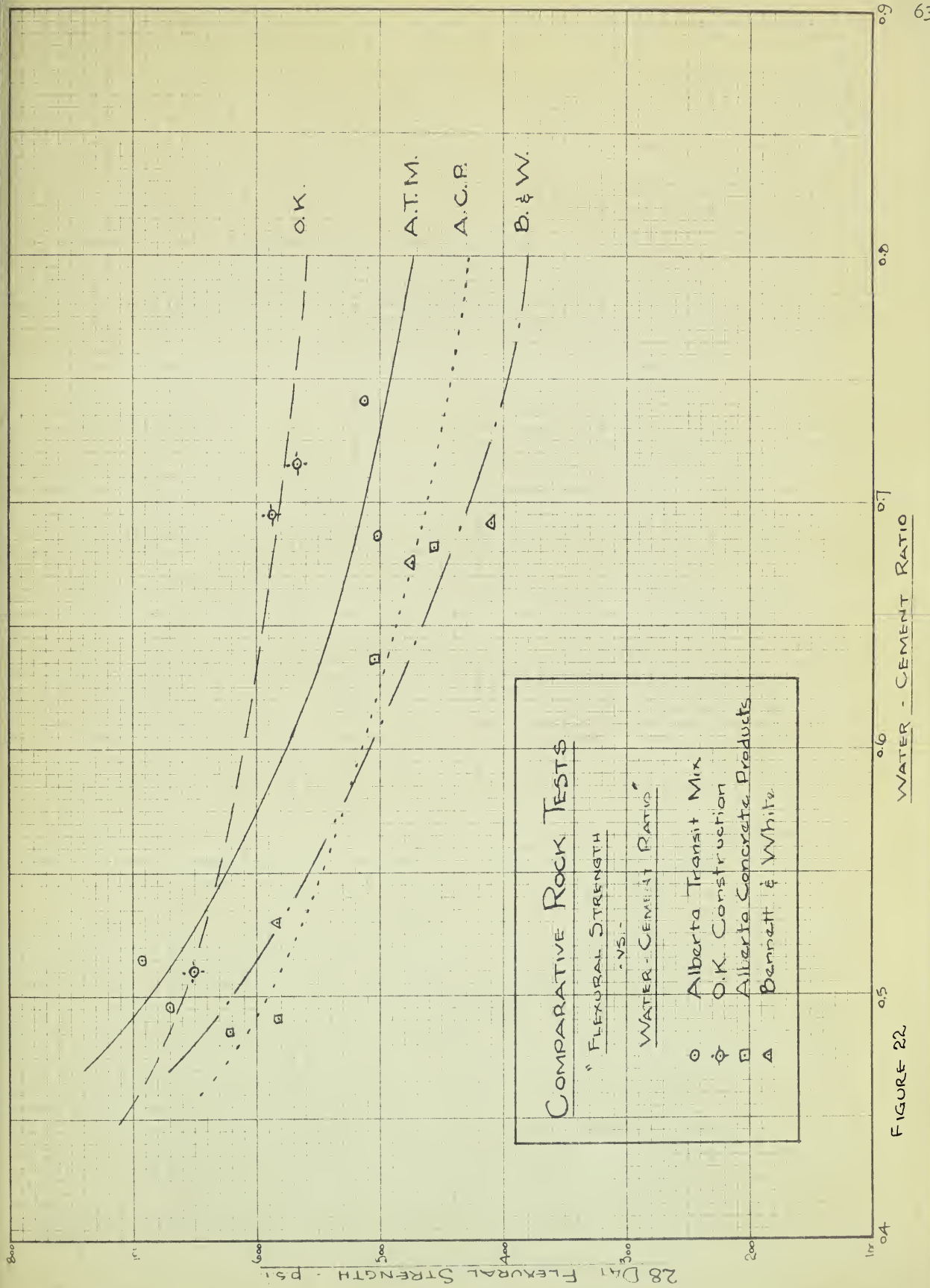


FIGURE 22

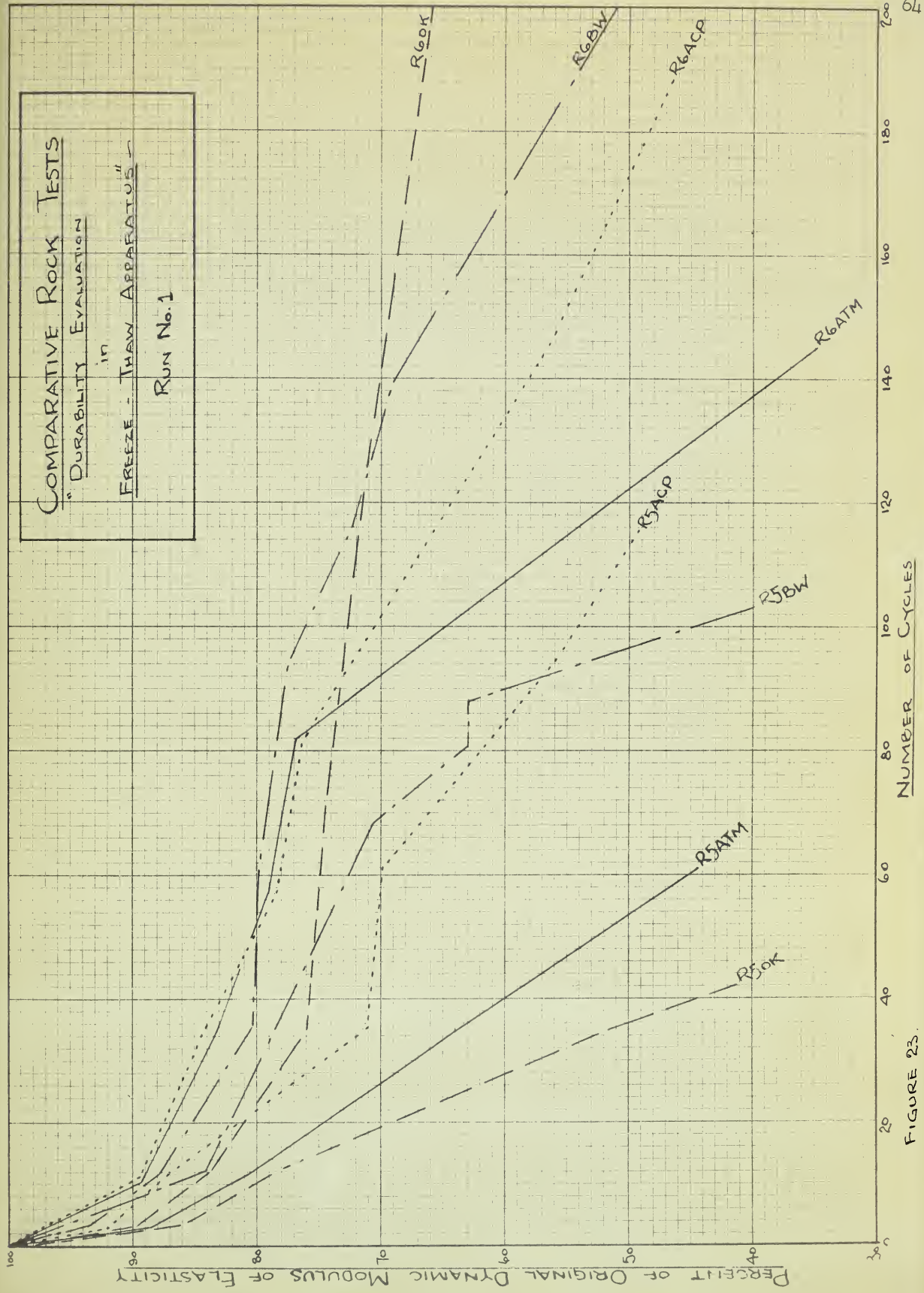


FIGURE 23.

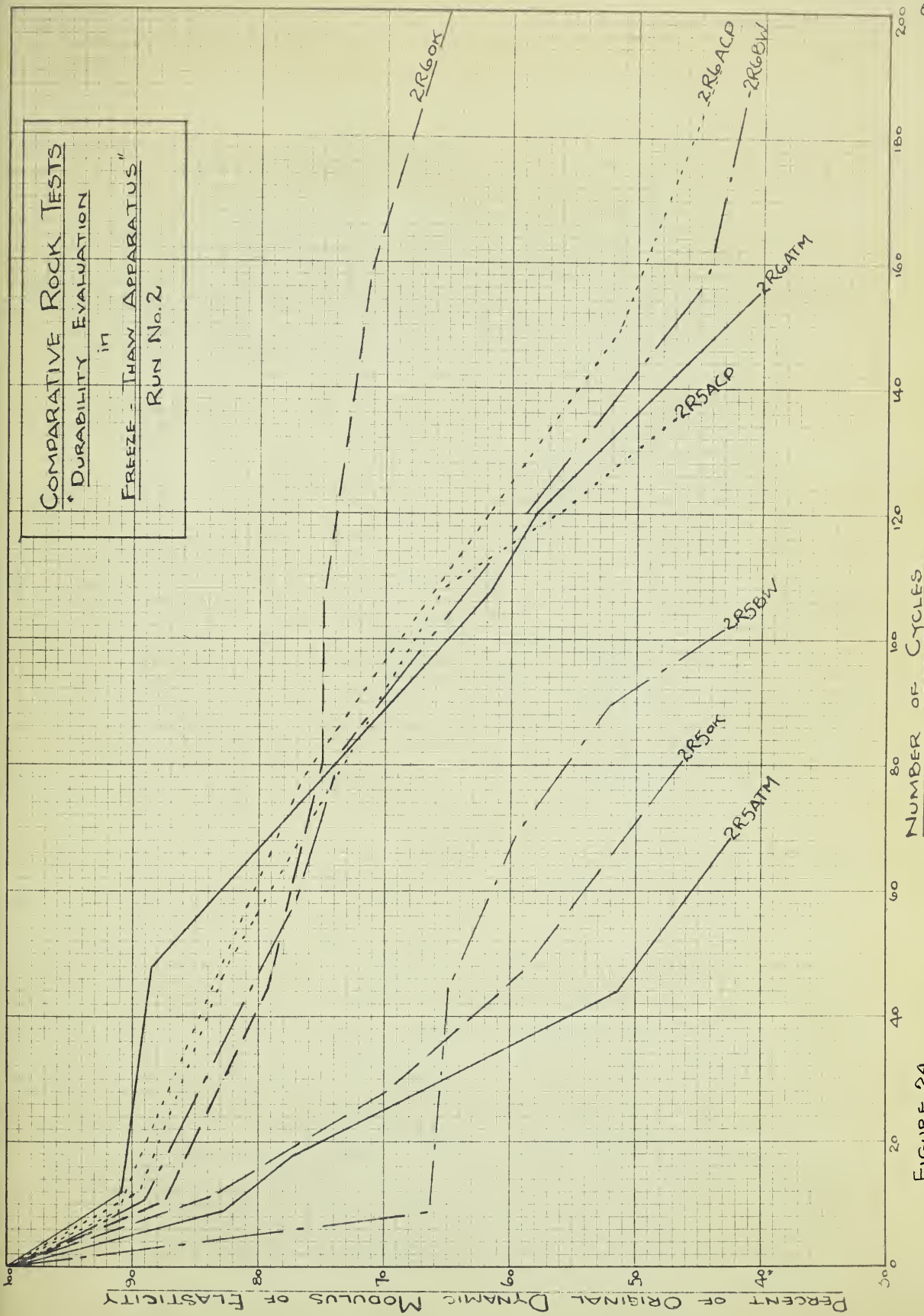


FIGURE 24.

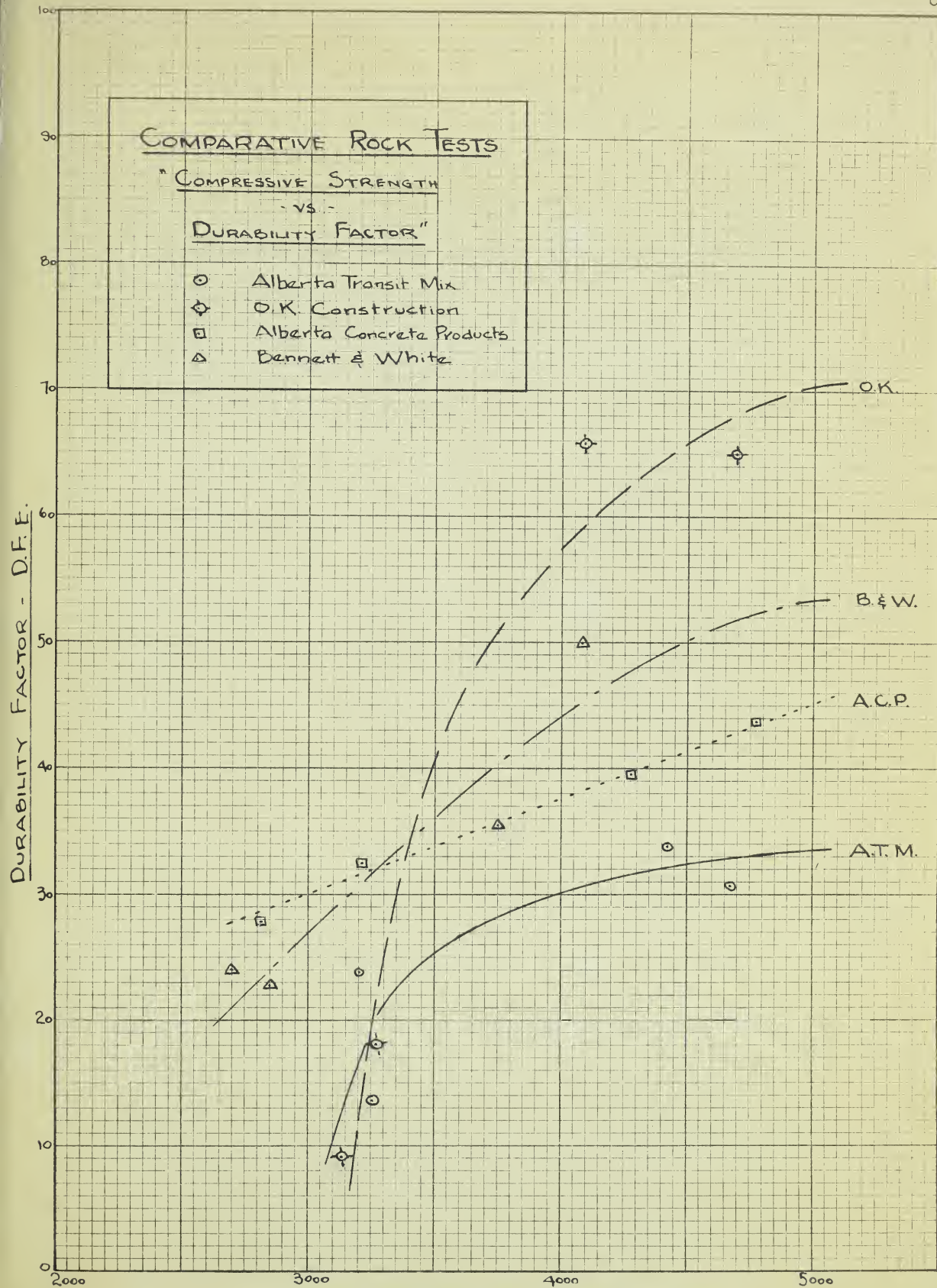


FIGURE 25 28 DAY COMPRESSIVE STRENGTH - p.s.i.

COMPARATIVE ROCK TESTS

"WATER - CEMENT RATIO"

-V3-

DURABILITY FACTOR

- Alberta Transit Mix
- ◇ O.K. Construction
- Alberta Concrete Products
- △ Barnett & White

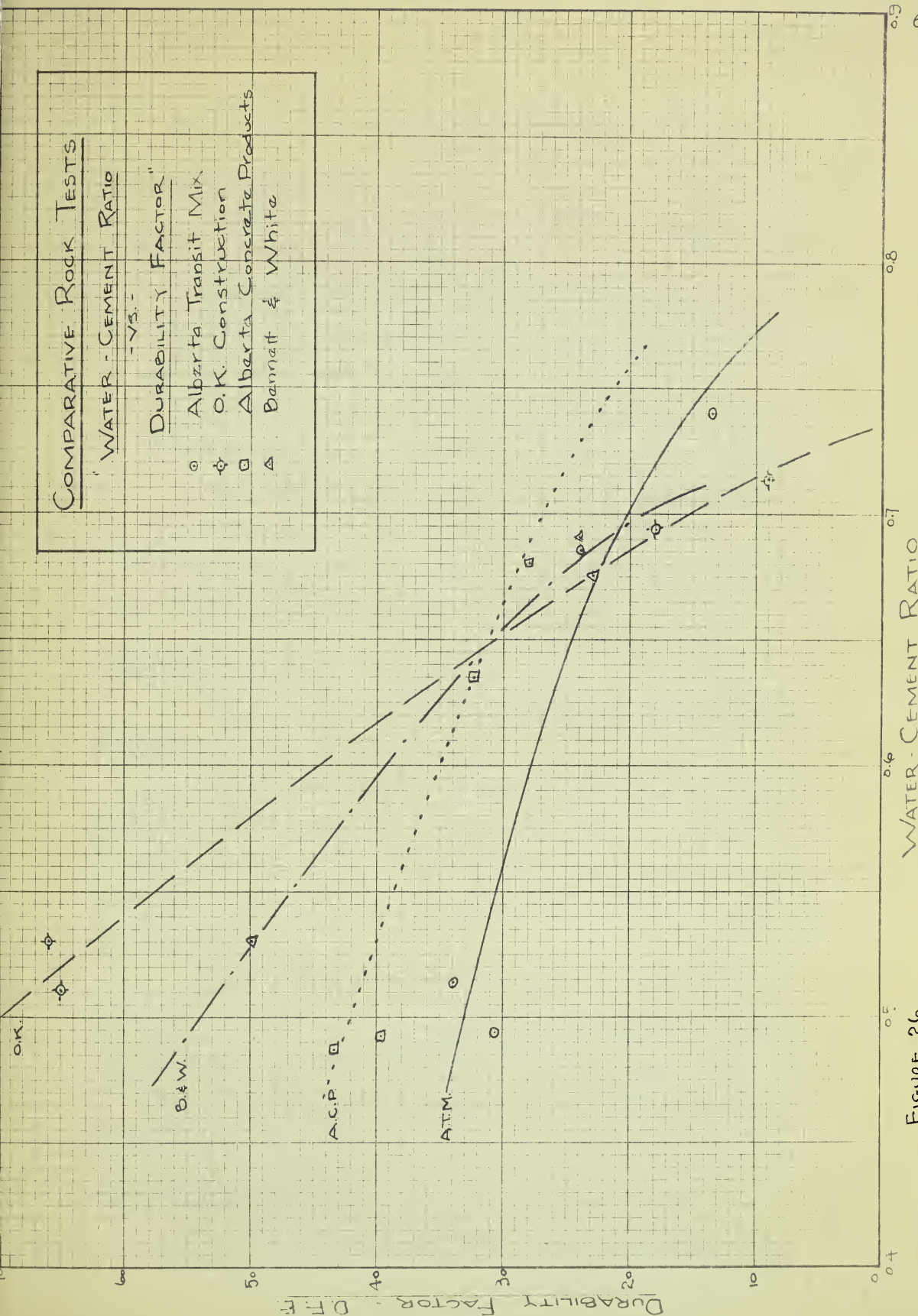


FIGURE 26

RESULTS OF ROCK EVALUATION TESTS

Compressive Strength Tests

A plot of Compressive Strength versus W/C Ratio for all of the rocks tested is shown in Fig. 21 .

The Alberta Transit Mix Rock shows the best compressive strength, giving a compressive strength of about 4600 p.s.i. at 28 days for a W/C ratio of 0.5.

The curve for O.K. Construction Rock runs fairly close to the Alberta Transit Mix but is about 100 to 150 p.s.i. below it.

The Alberta Concrete Products and the Bennett and White Rocks are fairly close to each other but are both about 500 p.s.i. below Alberta Transit Mix Rock, with the Bennett and White Rock being slightly below the Alberta Concrete Products Rock.

Flexural Strength Tests

Fig. 22 is a plot of 28 day Flexural Strength versus W/C Ratio.

In this case the O.K. Construction Rock shows the highest curve except for lower values of W/C, (less than 0.5), where it tends to flatten slightly. The Alberta Transit Mix Rock is generally slightly below O.K. Construction Rock, being about 50-75 p.s.i. lower than O.K. Construction.

Alberta Concrete Products and Bennett and White Rocks are once again both below O.K. Construction Rock with Bennett and White being the lowest for higher values of W/C ratio, (greater than 0.60), and Alberta Products dropping below Bennett and White for values of W/C ratio less than 0.60.

Durability Evaluation Tests

As in the sand evaluation tests investigations were run on

two beams for each different sand and for each different cement content, that is, Run No.1 and Run No.2.

Testing was continued until the Modulus of Elasticity had decreased to 50% of the original, or until 200 cycles had been run. Two graphs of 'Percent of Original Dynamic Modulus of Elasticity versus Number of Cycles' were drawn, one for each run. These are shown in Figs. 23 and 24 .

The two sets of results check fairly closely in general.

It will be noted from the two graphs that though there is a considerable increase in durability from the 5 bag mix to the $6\frac{1}{2}$ bag mix, there does not exist quite so sharp an increase as did exist in both the Fineness Modulus Tests, (Figs. 12 and 13), and in the Sand Evaluation Tests, (Figs. 17 and 18). The main reason for this seems to be that in all cases the 5 bag mixes did not drop as rapidly in durability as they did in the other tests.

We would expect this to happen since the standard sand used in all the mixes was Doncaster Pit Run and, from the Sand Evaluation Tests, we know that this sand shows considerably better characteristics than any of the other available sands.

It is very interesting to note that in both sets of tests the $6\frac{1}{2}$ bag mixes of O.K. Construction Rock show the highest durability, whereas the 5 bag mixes of the same rock show the lowest durability. This seems very strange since, in nearly all the other cases, a rock-- or a sand, for that matter--showing low durability for low cement content, tends to show relatively low durability for higher cement contents.

The only explanation for the strange behavior of the O.K. Construction Rock is that this aggregate was the last to be tested.

During the testing of this aggregate difficulties were encountered in both the freeze-thaw apparatus and in the sonic apparatus. The freezing solution was not functioning properly because too much alcohol had evaporated from it and as a result the refrigeration plates continually became coated with a thick layer of ice. At the same time the contact microphone pickup in the sonic apparatus broke down and a crystal pickup was used in its place. This pickup was too sensitive to harmonics, and consequently was not very satisfactory.

Because of these difficulties, it is felt that the results of the O.K. Construction aggregate tests are not very reliable.

As in the case of the Elk Island Sand, the Alberta Transit Mix Rock, which showed very favorable compressive strength and flexural strength characteristics, does not show such good durability properties. For this rock the durability factor is about 50% smaller than Alberta Concrete Products and Bennett and White Rocks for the 5 bag mixes, and about 75-100% smaller for the $6\frac{1}{2}$ bag mixes.

The Alberta Concrete Products and Bennett and White Rocks seem to show about the same durability factors. Both are about 50% higher than O.K. Construction Rock for 5 bag mixes, and about 50% lower than O.K. Construction Rock for $6\frac{1}{2}$ bag mixes.

From the plots of 'Durability Factor versus 28 day Compressive Strength', (Fig. 25), and 'Durability Factor versus W/C Ratio', the listing of the rocks tested in order of decreasing durability factor is:-- O.K. Construction Rock, Bennett and White, Alberta Concrete Products, and Alberta Transit Mix. It should also be noted from these two graphs that a definite break in the rate of change of durability factor at a compressive strength of about 3000 - 3500 p.s.i., or at a W/C ratio of about 0.70 takes place. For lower values of compressive

(1) Fig. 26

strength than these the durability factor decreases very rapidly, whereas for higher values the rate of increase of DFE begins to slow down. Thus it would seem to be well worthwhile, from a durability standpoint, to design mixes for at least 3000 and, preferably, 3500 p.s.i.

SUMMARY AND CONCLUSIONS

Summary

Several sands and gravels from the Calgary and Edmonton areas were investigated and evaluated. A complete set of preliminary investigations were run on each material according to the A.S.T.M. specifications, and then a series of mixes were designed according to the A.C.I. Standard Design Procedure in which each of the sand types was incorporated into concrete, using a particular gravel, followed by each of the rock types, using a particular sand. Evaluation was based on compressive strength tests, flexural strength tests and durability in freeze-thaw apparatus.

Conclusions

A. General

1. Compressive strength and flexural strength tests are not an indication of durability. Aggregates giving very favorable compressive and flexural strengths may show very low durability factors.

2. For a particular set of materials durability depends on the cement content. For low values of cement content the durability factor is very sensitive to changes in cement content. For higher values of cement content, (greater than about 6 bags per yard), slight changes in cement content do not affect the durability factor to such a great extent. It is therefore advisable to use a cement content such that the latter relationship exists. Design to a minimum strength of 3000 p.s.i. will accomplish this.

B. Sand Tests

1. Doncaster Pit Run Sand and Elk Island Sand showed the

best compressive and flexural strengths. Doncaster Pit Run also showed the best durability, but Elk Island sand dropped very sharply here, showing only medium durability .

2. Doncaster Washed Sand showed comparatively low compressive strengths but showed considerably better durability, being slightly below Doncaster Pit Run Sand.

3. The group of sands from the Calgary area showed, in general, poorer qualities than those from the Edmonton area. Dewinton Sand showed the best compressive and flexural strengths but the mixture of $\frac{1}{2}$ River and $\frac{1}{2}$ Dewinton showed much better durability than Dewinton alone.

4. Clarke's Sand was the poorest sand of all. This sand showed the poorest flexural and compressive strengths, and also the poorest durability, having a maximum DFE even for $6\frac{1}{2}$ bags of cement per yard of about '3'.

c. Gravel Tests

1. Alberta Transit Mix Rock showed the best compressive strengths, and was only slightly low in flexural strengths. However, it dropped considerably in the durability tests, showing only about one-half the durability shown by O.K. Construction and Alberta Concrete Products.

2. O.K. Construction Rock showed the best durability for higher cement contents. This rock also showed excellent compressive and flexural strengths and, in general, was the best of all of the rocks tested.

3. Alberta Concrete Products Rock, though fairly low in compressive and flexural strengths, showed very good results in durability tests. It was only slightly below O.K. Construction Rock in these tests.

4. Bennett and White Rock was in general the poorest of the rocks tested. It was the weakest of all the rocks in the compressive and flexural strength tests, but indicated fairly good durability. Its durability was very close to that of Alberta Concrete Products Rock.

PART III

SCALING TESTS

Introduction

NaCl and CaCl_2 are commonly used during the winter months for the purpose of removing ice from city streets. The concentration of CaCl_2 is particularly great at street intersections and hills. Traffic tends to pick up the CaCl_2 at these points and distribute it over a large number of side streets. Thus, the effect of CaCl_2 on the scaling of concrete is widespread. Because of this fact numerous tests have been conducted with the object of determining some method of increasing the resistance of concrete slabs to surface scaling.

In the general program of investigation of air-entraining agents there have been included several studies of the effect of air-entrainment on the resistance of concrete to CaCl_2 scaling. Most of these tests have found that the entrainment of 3.5% air considerably increases the resistance of the concrete to CaCl_2 scaling. In fact, tests conducted by the Portland Cement Association^(1&2) and other organizations⁽³⁾ have shown increases in resistance of concrete to scaling up to several hundred per cent due to the entrainment of air.

- (1) Proceedings of the American Concrete Institute, Volume 33, 1937--
'Effect of CaCl_2 and NaCl on Concrete when used for Ice Removal'--
H.G. Gonnerman
- (2) Proceedings of the American Concrete Institute, Volume 39, 1943--
'Influence of Sand, Cements and Manipulation upon Resistance of Concrete to Freezing and Thawing'--W.C. Hansen
- (3) Engineering News Record, October 1940, Volume 125--'Pavement Scaling Successfully Checked'--O.L. Moore

However, in a series of tests run at the University of Alberta⁽¹⁾ it was found that concrete slabs with entrained air ranging from 4.5% to 7.0% showed increases in CaCl_2 scaling resistance of barely 200%. The only difference between the two series of tests was that the Portland Cement Association carried out the scaling tests on a trowelled surface, whereas the University of Alberta carried out the tests on a wood-formed surface.

As a result of this discrepancy in test results, it was felt that a further series of CaCl_2 scaling tests were necessary to analyze more completely the effect of CaCl_2 on different types of surface finishes and different cement factors, as well as entrained air.

(1) 'An Investigation of Air-entrainment in Concrete and its Effect on Durability'-- K.R. Lauer, Thesis for M.Sc. Degree, University of Alberta, 1948

Specimens

Each specimen consisted of a concrete slab having dimensions of 15" x 6" x 2". A 1" x 1" dyke was formed around one surface either by building up the centre portion of the bottom of the form, (as in the case of Lauer's work), giving a wood-formed surface to test, or by building up dykes of 1:2 mortar by weight on the top surface 2 hours after placing the concrete.

The aggregate used for all slabs was Alberta Concrete Products Gravel and Doncaster Washed Sand. Mixes consisted of the following designs:

5S-N --	Standard A.C.I. design -- 5 bag per yard mix Slump = 4"
5S-A --	Standard A.C.I. design -- 5 bag per yard mix including 4% air by air-entrainment Slump = 4"
7S-N --	Standard A.C.I. design -- 7 bag per yard mix Slump = 4"
7S-A --	Standard A.C.I. design -- 7 bag per yard mix including 4% air by air-entrainment Slump = 4"

Ayr-trap was the air-entraining agent used in every case.

A summary of the actual mix proportions used and other relevant data will be found in Fig. 16.

Each different mix design was tested for four different types of surface finishes:

- a) Wood-formed surface, (similar to Lauer's work).
- b) Wood trowelled within 10 minutes after concrete was poured.

c) Burnished with steel trowel when surface water had evaporated and concrete was nearly hard.

d) Wood trowelled within 10 minutes after concrete was poured. Given linseed treatment after 10 days of curing in moist room.

A repeat run was made of each different type of slab tested making a total number of 32 slabs tested.

Testing Procedure

All test specimens were made up using the same standard procedure. The wooden forms were given a thin coat of vaseline to facilitate stripping. The forms were then filled with concrete, rodded 25 times, and each surface was given its desired type of finish. The slabs were then placed in the moist room where they were left to cure for 24 hours, after which time they were stripped of the forms. All of the (a), (b) and (c) type surfaces were left to cure in water for 13 days, then in air for the next 14 days. They went into the refrigerator on the 28th day after being poured. The (d) type surfaces were allowed to cure in the moist room for 10 days, and were then treated with a mixture of 50% boiled linseed oil and 50% turpentine at the rate of about 50 square yards per gallon, followed in 24 hours by an application of neat boiled linseed oil at the rate of about 70 square yards per gallon. These slabs were then allowed to cure in air until they were taken into the refrigerator on the 28th day after they had been poured.

Once a slab was in the refrigerator a 1/4" layer of water was poured on its surface and allowed to freeze overnight. After approximately 18 hours of freezing, 60 grams of CaCl_2 , (corresponding to about 3 lbs. per square yard), was sprinkled over the ice.

The slab remained in the cold room during the following 6 hours under the thawing action of the CaCl_2 . During the last hour of thaw the slab was taken outside, washed clean of CaCl_2 solution, and the surface brushed with a wire brush.

The slab was then returned to the refrigerator, a fresh $1/4$ " layer of water was poured on the surface, and the cycle repeated. These cycles were repeated every day, except during Sunday, when the slab was allowed to remain frozen for some 42 hours.

The calcium chloride used was of the same stock used last year. A chemical analysis of the lot indicated the calcium chloride to be of very good quality, having only 0.21% of sodium sulphate. A high percentage of sodium sulphate in salts used would increase the rate of surface scaling considerably.

A visual examination was made of each slab after each cycle of freezing and thawing with calcium chloride. A code was set up to indicate the extent of the scaling of the surface.

Code for Evaluating Amount of Surface Scaling

- F.S. = Fine scaling--scaling off of a fine layer of cement paste from the slab surface.
- L.S. = Light scaling--scaling off of a thin layer of fine aggregate exposing the coarser particles of fine aggregate as well as the coarse aggregate very near the surface.
- M.S. = Medium scaling--scaling off of fine aggregate, exposing the coarse aggregate.
- H.S. = Heavy scaling--scaling off of layers of fine aggregate exposing the coarse aggregate to a quarter of its thickness.

Note: Each main division was subdivided into 25%, 50%, 75% and 100% according to the extent of area over which the type of scaling applied.

CONCRETE DATA--SCALING TESTS

Mix No.	Date Cast	<u>Mix Proportions per Cubic Yard</u>				W/C Ratio	Slump ins.	Flow %	Air Content	Workability	<u>(1)</u> <u>Comp. Stgth.</u>	
		Cement lbs.	Sand lbs.	Gravel lbs.	Water lbs.						7 Day psi	28 Day psi
5S-N	July 27/48	434	4.95	1500	1665	323	none	0.755	3½	110	1.10	E -- --
25S-N	July 29/48	440	5.06	1480	1710	303	none	0.694	3	120	1.50	V.G. -- --
5S-A	July 27/48	433	4.94	1470	1680	280	218 cc. Ayrtrap	0.645	4	110	4.30	E -- --
25S-A	July 29/48	436	4.98	1460	1700	272	212 cc. Ayrtrap	0.625	3	110	4.10	E -- --
7S-N	Aug. 3/48	604	6.90	1460	1660	280	none	0.465	4½	115	1.0	E 2390 3750
27S-N	Aug. 10/48	598	6.83	1450	1650	294	none	0.490	4	120	1.10	E 2600 4080
7S-A	Aug. 3/48	613	7.01	1370	1675	270	213 cc. Ayrtrap	0.437	4	95	4.00	E 2400 3790
27S-A	Aug. 10/48	611	6.98	1410	1680	263	214 cc. Ayrtrap	0.440	3	100	3.80	E 2680 --

TABLE 16

(1) Average of 2 cylinders.

PERCENT SURFACE SCALING

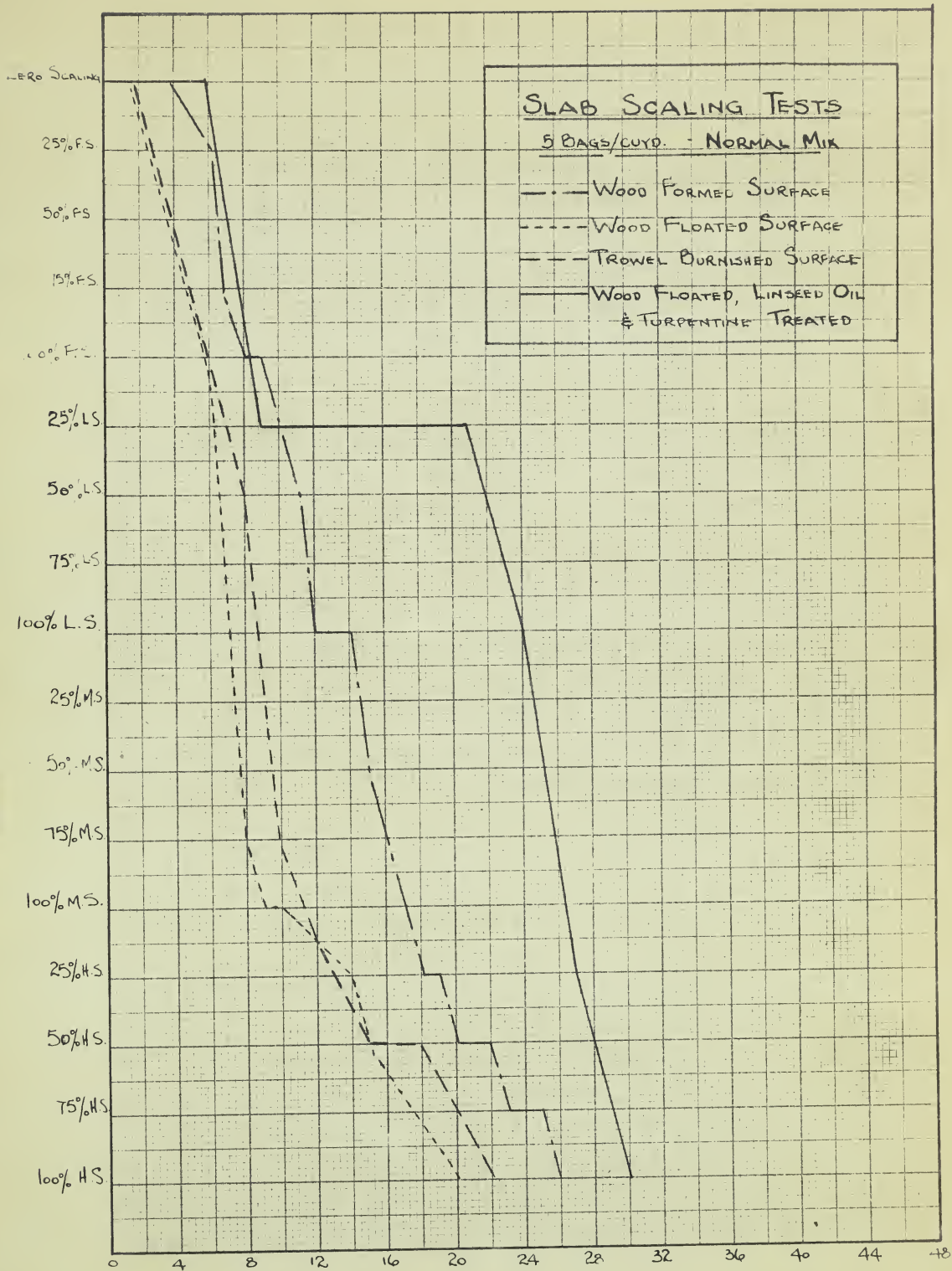
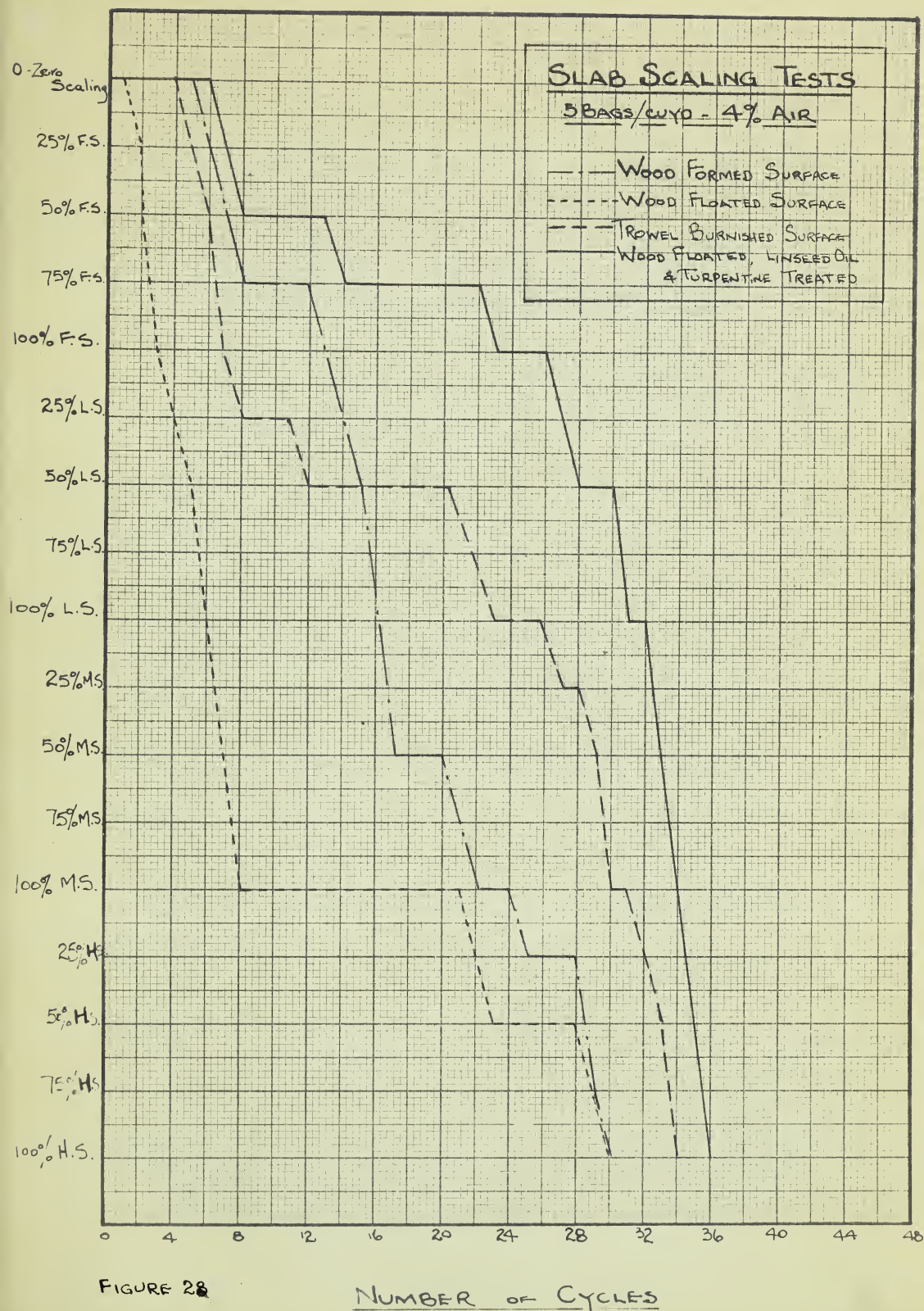
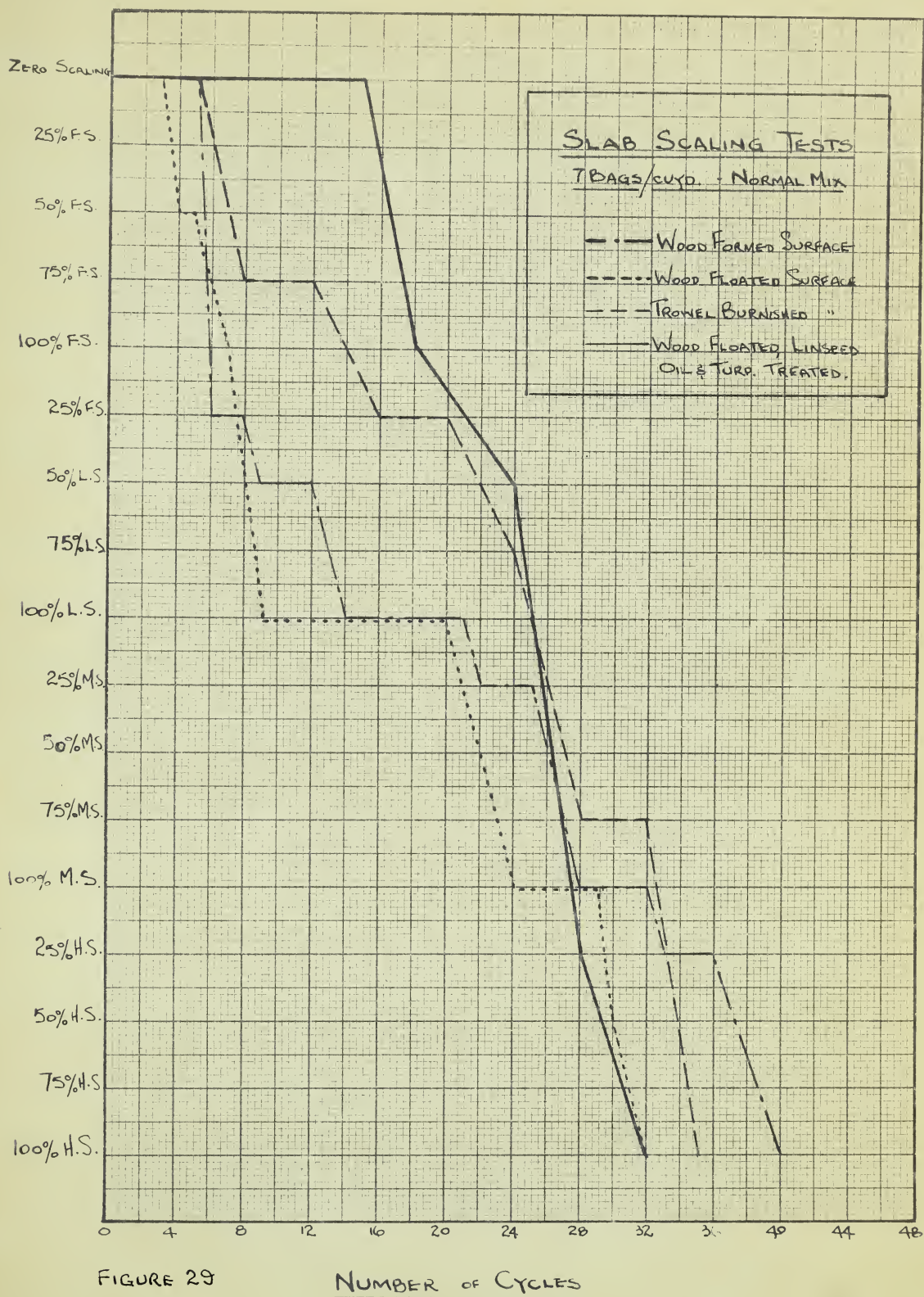


FIGURE 27

NUMBER OF CYCLES



PERCENT SURFACE SCALING



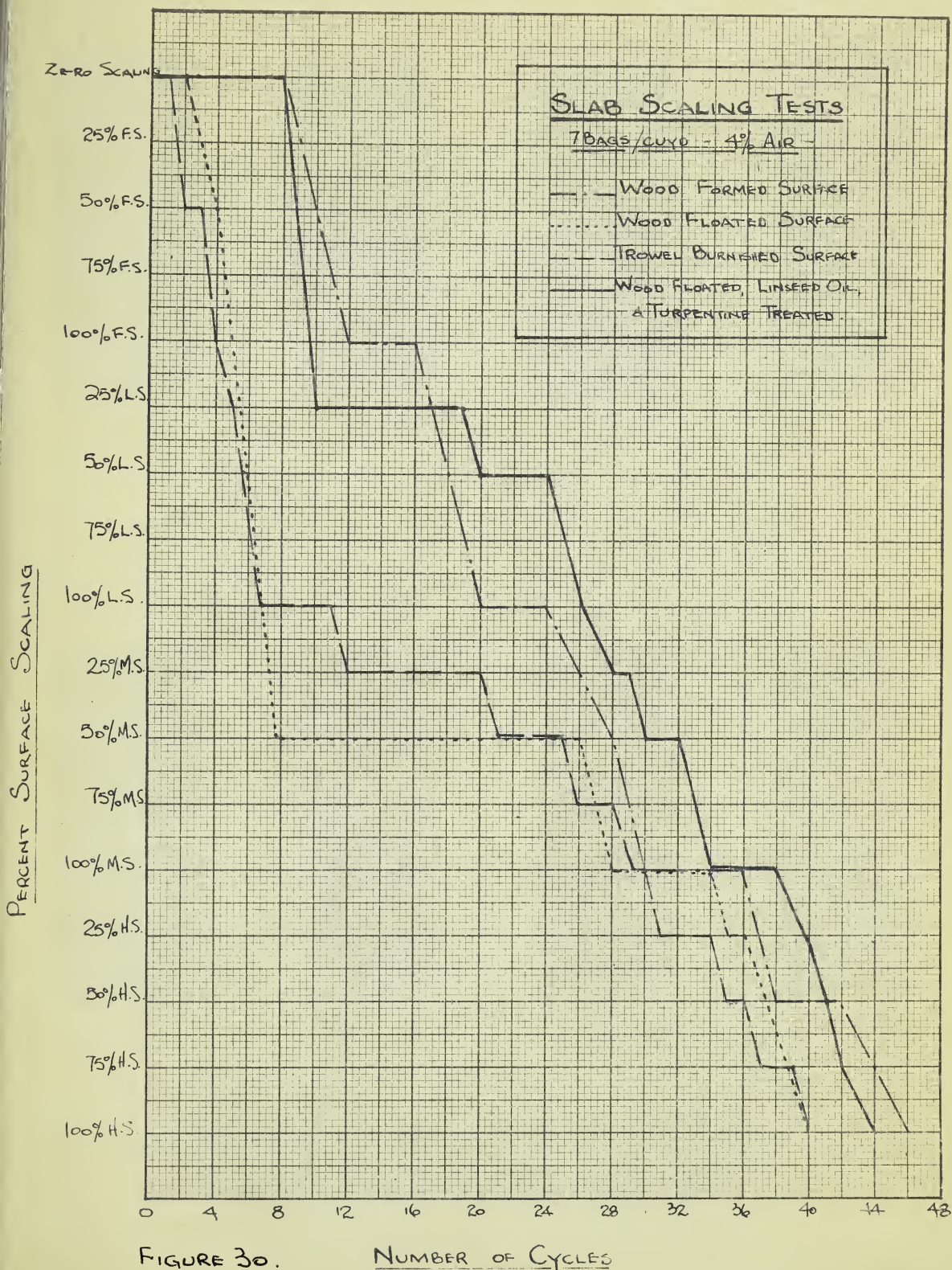


FIGURE 30.

NUMBER OF CYCLES



0 CYCLES



2 CYCLES



4 CYCLES



6 CYCLES



8 CYCLES



10 CYCLES



15 CYCLES



20 CYCLES

FIGURE 31 . SURFACE SCALING TESTS

CEMENT FACTOR 5 BAGS/YD. . NORMAL MIX.

WOOD FLOATED SURFACE.

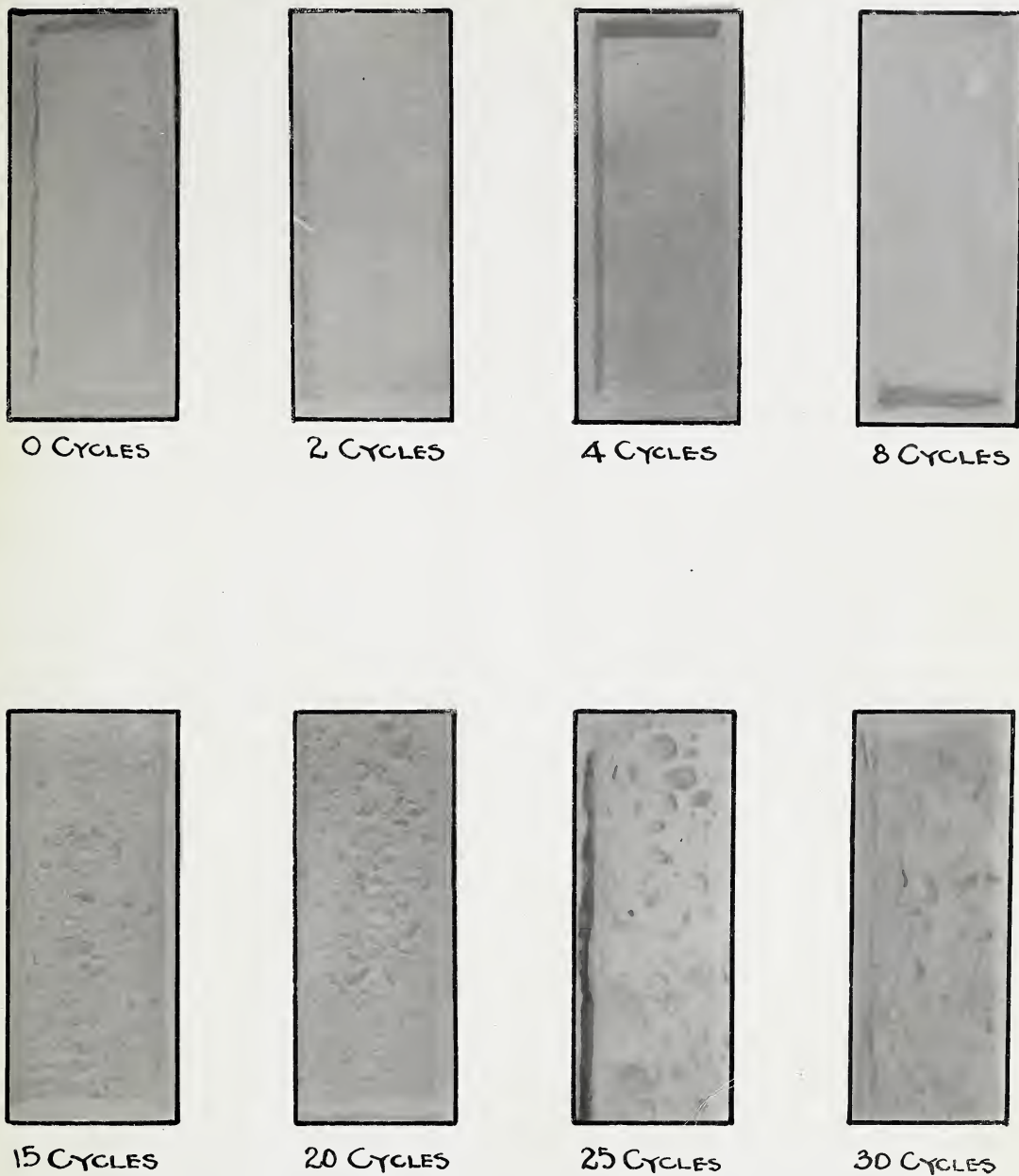


FIGURE 32. SURFACE SCALING TESTS

CEMENT FACTOR 5 BAGS/YD. NORMAL MIX.
LINSEED OIL & TURPENTINE TREATED SURFACE

Discussion of Results

The comparative results of the resistance to CaCl_2 scaling shown by the different mixes and different types of surface finishes are best seen in Figs. 27 to 30, (Graphs of slab scaling tests).

It is interesting to note that, of the 5 bag mixes, those mixes containing approximately 4% entrained air showed an increase of about 150% to 200% in CaCl_2 scaling resistance over the normal mixes. This is about the same result as that obtained last year. On the other hand an increase in the cement factor, (7 bags per cubic yard), showed as much, if not more, percentage increase in scaling resistance as the entrainment of 4% air. In other words, a mix using about 7 bags per cubic yard with no entrained air showed about the same scaling resistance as a mix using 5 bags per cubic yard with 4% air entrained. The greatest general resistance to CaCl_2 scaling was indicated by the slabs made with 7 bags per cubic yard and containing 4% entrained air. These slabs showed about 150% increase over the 7 bag normal mix and about 250-300% increase over the 5 bag normal mix.

In comparing the effects of different surface finishings it will be generally noted from all of the graphs that the linseed oil and turpentine-treated surfaces, during the early stages of the test, showed by far the greatest scaling resistance properties.

However, after about 10 - 15 cycles of freezing and thawing, this surface showed a general tendency to break down very rapidly, in large layers, ending up at the end of the test showing very little, if any, increased resistance to scaling.

It is the author's opinion that the surface coating of linseed oil and turpentine tends to minimize the effects of the early stages

of surface breakdown but the damage, nevertheless, seems to be proceeding underneath the surface layer, until it finally reaches a stage where the whole surface layer tends to break down very rapidly. As a result of such action it would seem that the extra cost of extensive linseed treatment would hardly be practical; instead, the same money would be much better spent if put into increasing the cement factor, or by using air-entrainment.

Of the other three types of surface finishings tested there does not seem to be enough evidence from this particular series of tests to favor any one above any other. In general, the wood-floated surface, (surface b), seemed to show the most rapid signs of breakdown. But it characteristically slowed down its rate of disintegration at about 50% Medium Scaling, and finally ended up exhibiting nearly as much scaling resistance as any other type of surface finish.

The steel burnished surface, (surface c), showed in general much the same characteristics as did surface 'd', (linseed treated), that is, it seemed to withstand breakdown for some time, and then suddenly started to break down quite rapidly. Once again, it would seem that the same explanation would apply in this case as in the case of surface 'd'.

This series of tests still does not show anywhere near the remarkable increases in CaCl_2 scaling resistances as reported by the Portland Cement Association. The only variable that cannot be accounted for is the vigor with which the surfaces are scrubbed between each cycle. In this test surfaces were scrubbed with a 2" x 6" steel brush for about 1 minute using a pressure of about 15 lbs. That this is too severe does not seem very likely. A more detailed account of the handling of slabs in the Portland Cement

Association tests would perhaps reveal the reason for such variation in results.

Summary

Four different concrete mix designs were tested for resistance to CaCl_2 scaling. Each design was tested using a total of 4 different types of surface finishes making a total of 16 slabs. The whole procedure was repeated once as a check, making a total of 32 slabs tested.

The four different designs were as follows:

- a) 5 bags of cement per yard, normal mix
- b) 5 bags of cement per yard, 4% entrained air (with Ayr-trap)
- c) 7 bags of cement per yard, normal mix
- d) 7 bags of cement per yard, 4% entrained air (with Ayr-trap)

Each design was tested with the following surface finishes:

- a) Wood-formed surface
- b) Wood-floated surface
- c) Steel burnished surface
- d) Surface treated with Linseed Oil and Turpentine

A layer of ice was allowed to freeze on the surface of each slab and was then thawed with CaCl_2 . These cycles were repeated every day with visual examination being made between each cycle. The test was ended when 100% High Scaling was reached.

Conclusions

1. Definite increase in resistance to CaCl_2 scaling is shown by entraining 4% air. An increase of 150% to 200% was shown by both the 5 and 7 bag per yard mixes when made with 4% air.

2. The 7 bag normal mixes showed about 200% more resistance to scaling than the 5 bag normal mixes. This indicates that an increase in cement content gives an increase in scaling resistance.

3. Both the steel burnished and turpentine treated surfaces showed high resistance to scaling during the early stages of the test but then broke down very rapidly in the latter stages, showing at the end very little increase in resistance over the wood-formed and floated surfaces. Thus the type of surface finish did not indicate any great influence on the resistance of the concrete to scaling.

4. The results of this test, though slightly better than those obtained in the tests conducted here last year, still do not show anywhere near the improvement for air-entrained mixes as reported by the Portland Cement Association.

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